THREE YEARS' EXPERIENCE

OF

WATER PURIFICATION BY MEANS OF IRON

IN

ANDERSON'S REVOLVING IRON PURIFIER.

BY

E. DEVONSHIRE,
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RESIDENT ENGINEER AND MANAGER
TO THE ANTWERP WATERWORKS COMPANY, LIMITED.

3, WHITEHALL PLACE, LONDON, S.W.
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PREFACE.

It is now somewhat more than three years since the mode of purifying large volumes of water by means of iron, described in the following pages, was perfected and patented by Mr. W. Anderson, M. Inst. C.E., of the firm of Messrs. Easton & Anderson, of London and Erith, and first applied to the purification of the impure and highly coloured waters of the river Nethe, which the Antwerp Waterworks Company had, from want of a better, been compelled to utilise as their source of supply. The writer has had special opportunities of watching the practical working of Mr. Anderson's invention from its experimental stage to the present, and has also personally supervised the experiments carried out at Paris, Gouda, Dordrecht, and Ostend, which have led to the permanent adoption of this system of purification in the first three cases, and to the decision to adopt it in the last. In conjunction with Professor Kemna, Doctor of Sciences, of Antwerp, the writer has also made numerous experiments in the laboratory of the effect of this process upon waters differing widely in character. He therefore thought that as the most complete answer to the frequent inquiries he receives, and for the information of those engineers and others who are interested in water and sanitary questions, it would be of interest to publish the results of his three years' observations.

E. D.

Antwerp, *May* 1888.

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PART I.

INTRODUCTORY REMARKS.

Of the various sources of water supply for cities or towns, the most convenient as well as the most ample source is, in the vast majority of cases, the river on the banks of which the city or town has sprung up; the sites chosen for what are now thickly populated centres, having doubtless been determined originally by a consideration of the facilities afforded by the proximity of a river.

Rivers as sources of supply generally possess the great advantage of being able to yield the largest quantities of water within the shortest distances. Increase of population and of manufactures, and improved sanitation by means of systems of water-borne sewage, have, however, in very many cases become causes of pollution, and have made it necessary to sacrifice the advantages of the convenience and abundance of this source of water supply to its impurity.

Sand filtration is frequently not sufficiently effective to ensure, under all circumstances, a potable and hygienically pure water; and of the various methods of chemical purification attempted, most are not always harmless, and their cost generally precludes their adoption, except on a small scale.

To restore to a river its original superiority over other sources, a material is required capable of purifying sewage effluents, the waste water from factories, and the river water itself before it finds its way to the consumer. This material should be chemically harmless in its action, and capable of application to large volumes of water at a low cost.

The powerful purifying effect produced on water by metallic iron has been recognised for many years past, and has led to several attempts to apply it not only to domestic use, but also on the large scale for the supply of towns.

Until recently, however, all these methods have been based upon the principle of bringing the water into contact with the iron, either by letting it flow over plates or rods, or more generally by filtration through a layer of more or less finely divided granules of one or the other of the specially-prepared forms of the metal. Among the most successful of the latter is the so-called "spongy iron," patented some twenty-five years ago by Professor Bischof, and very extensively used in the domestic filters of the Spongy Iron Filter Company.

The acknowledged efficiency of Professor Bischof's material as a purifier of water led Messrs. Easton and Anderson, acting upon the advice of Mr. G. H. Ogston, F.C.S., to make use of it on a large scale in the construction of the filters of the Antwerp Waterworks in 1880. It is not necessary to enter here into a full account of the arrangement and working of these filters, a detailed description of which will be found in a paper read before the Institution of Civil Engineers in 1882.* Suffice it to say that the very activity of the spongy iron as a purifying medium, eventually caused such a choking of the pores of the filters as to create serious difficulties in their practical working. The oxides of iron formed by the action of the metal on the water, added to the carbonates of lime precipitated,

* 'The Antwerp Waterworks,' by W. Anderson. Minutes of Pro-

and to what may be called the products of the purification of the water, gradually filled up the interstices between the granules of the material, and prevented the water from passing through, except in very variable and altogether insufficient quantities. But the excellent chemical and decolorising results obtained at Antwerp made the Water Company loth to give up the use of iron as a purifying medium. Numerous experiments were made under the direction of Mr. Anderson, Mr. Ogston, and Professor Bischof, with a view to maintaining the permeability of the spongy iron filters, and to ensuring the regularity of their working, but without success. Finally a suggestion emanating from Sir Frederick Abel, C.B., F.R.S., led Mr. Anderson to hit upon that method of applying metallic iron to the purification of large volumes of water of which his Patent Revolving Iron Purifier is the outcome.

Rapidity of the action of iron on water.—It had been supposed, when designing the Antwerp filters on Professor Bischof's system, that forty-five minutes' contact between the metal and the water was necessary for effective purification. Some of the first experiments with the revolving purifier proved, however, that, when maintained in a state of agitation by suitable means, iron acts on water with much greater rapidity than this. In fact it was found during the earliest experiments that an experimental 4-inch revolving purifier delivering 166 gallons per minute, and giving a contact of only 3½ minutes between iron and water, gave a better chemical result than one of the spongy iron filters of 8000 square feet area and 3 feet deep, through which the water was passing at a maximum speed of 1 foot per hour—thus giving a contact of three hours—both purified waters being afterwards filtered by identically similar sand filters.

It was further ascertained that when used in revolving purifiers, waste or scrap iron, such as cast-iron borings or turnings and the burrs from punching machines, were no less efficient than spongy iron, and were more suitable in form. A battery of revolving purifiers capable of dealing

with 2,000,000 gallons per day, and contained in a building 31 feet long by 26 feet wide, the whole plant costing 4000*l*., as originally erected at the pumping station of the Antwerp Waterworks, has proved competent to do twice the work of three spongy iron filters, having an area of 24,000 square feet, and the patent filtering material in which cost 8000*l*. The working expenses at the present time are also considerably less than formerly; so it will readily be admitted that an advance has been made in the practical and effective purification of large volumes of water.

For further and more detailed information as to the purifying action of iron, and the chemical results obtained, both on the small and the large scale, we would refer those interested in the scientific side of the question to:—

Minutes of Proceedings of the Institution of Civil Engineers, vol. lxxxi., Session 1884–85, part iii.—I. "The Purification of Water by means of Iron on the Large Scale." By William Anderson, M. Inst. C.E. II. "The Purification of Water by Metallic Iron in Mr. Anderson's Revolving Purifier." By George Henry Ogston, F.C.S., Assoc. M. Inst. C.E.

Journal of the Society of Arts, Nov. 26, 1886, vol. xxxv. —"The Purification of Water by Agitation with Iron and by Sand Filtration." By W. Anderson, M. Inst. C.E.

"L'Application Pratique du Fer à la Purification des Eaux Alimentaires." Par E. Devonshire, Assoc. M. Inst. C.E., Ingénieur de la Société des Travaux d'Eau d'Anvers.

"Ville d'Anvers: Rapport sur l'Eau de la Distribution pendant l'Été de 1885."

Also for the general question of iron as a purifier as compared with charcoal and other organic material, *vide* "Water and Health," published by the "Bischof Spongy Iron Filter Company."

I.—DESCRIPTION OF THE APPARATUS.

The principle of Anderson's Revolving Iron Purifier consists in the production of an intimate contact between metallic iron and the water to be purified, by the showering down of finely divided particles of the metal through an onward flowing stream of water.

The apparatus itself, as represented on Plate I., consists of a cylinder A, supported in a horizontal position by hollow trunnions B_1 B_2 revolving in pedestal bearings C_1 C_2, placed one at each of its extremities. Within the cylinder are a series of short curved shelves D D D arranged in steps at equal distances round its circumference and reaching from end to end. In the place of a sixth row of curved shelves is a line of small square plates H, H, H, which, by means of nuts outside the cylinder, can be set at an angle with the axis of the purifier. These plates serve to direct the shower of iron back towards the inlet end of the apparatus, and so to counteract the tendency of the current of water to carry the purifying material forward. Through the hollow trunnions, which are provided with stuffing-boxes, pass the ends of inlet and outlet pipes E and F, which bring and which carry off the water to be purified. Facing the inlet pipe E, is a circular distributing plate G, secured at a distance of $\frac{5}{8}$-inch or $\frac{3}{4}$-inch from the end of the cylinder, serving to distribute the water radially on its entering the "revolver," and prevent its flowing in a direct current along the axis of the apparatus. The inner end of the outlet pipe is fitted with an inverted bell-mouth K, carried down as near to the bottom of the cylinder as the shelves will allow, and intended to prevent the finer particles of iron from being carried out by the current of water. A rotary motion is given to the cylinder through gearing working into an annular spur-wheel I, surrounding one end of the cylinder.

Through a suitable hand- or man-hole J, iron in a moderately fine state of division is introduced into the

cylinder and spread evenly along the bottom in sufficient quantity to occupy one-tenth of the capacity of the cylinder.

When the Revolving Purifier is to be set in motion, the sluice-cock L, provided at the inlet, is opened and the cylinder filled with water, the air being expelled through the air-cock M, which at that time must be at the top of the cylinder. When all the air is expelled the air-cock is shut and the apparatus is set in motion by a small steam engine or other suitable form of motor, the speed of rotation being about 6 feet per minute at the periphery. By this rotary movement the shelves are successively caused to scoop up the iron granules, which at starting are spread evenly along the bottom of the cylinder, and to shower them down through the water. By means of the sluice-cock L, the flow of water may be regulated to the speed required to give the duration of contact with the iron found necessary for efficient purification under the particular circumstances. Regulation of contact is, however, generally effected by other methods to be described later on (*vide* Chap. V.). The sluice cock is required principally for isolating the apparatus when renewing the supply of iron in the cylinder.

On leaving the "revolver" the water requires to be aërated by exposure to the air, in order that the iron which has been dissolved may oxidise. For this purpose it is usually sufficient to allow the water to run along a shallow open trough direct on to the filter-beds, the water over the sand in which should be three or four feet deep, so that it might take some six hours in reaching the sand. A preferable arrangement, especially for bad water, is to deliver the contents of the revolvers into two, or better still three, settling ponds, each capable of holding six hours' supply, filling the ponds in succession, and decanting the water into the filter-beds by floating pipes from the surface. This arrangement prevents much of the impurities from settling on the surface of the sand in the filters, and so prolongs the time for which they will run without cleaning. With

some waters, and especially those coloured by peat, a great deal of aëration is necessary, in order completely to abolish colour and opalescence; in such cases air must be injected by means of a blower or pump, arranged to deliver a stream of air into the open trough through a perforated false bottom. In the rare cases where this is insufficient, a solution of perchloride of iron or of some other salts, added in minute quantities, will probably produce the desired effect.

II.—SPECIAL ADVANTAGES OF THE PROCESS.

Passing over, for the moment, the remarkable chemical improvement effected on water by its contact with finely divided metallic iron, and which will be more fully demonstrated in Part II., by the statement of actual results obtained on the large scale, we will now deal only with the special advantages of the revolving purifier from the mechanical, economical, and commercial point of view. These are:—

(*a*) *Uniformity of chemical action, and facility of regulation.*

(*b*) *Automatic cleansing of the iron granules, and constant renewal of their active surfaces.*

(*c*) *Removal of colour from water.*

(*d*) *Lowness of first cost and cheapness of working.*

(*a*) **A uniform and complete chemical contact** of the granules of iron is obtained with every part of the water to be purified. In the case of filter-beds composed of a chemically acting substance, this important condition is by no means so easily ensured. When filters have been at work for some time, first the surface layers, and gradually the whole depth of the active material become more or less choked, and the resistance to the passage of the water is increased. The water then seeks for itself the points of the filter offering the least resistance, and passes rapidly through the layer of the material at these

places, thus losing the benefit of a long and uniform contact. This cannot possibly occur in the revolving purifier, the shelves of which are constantly showering equal quantities of iron through a steady flow of water. The facility with which the rate of flow can be regulated is self-evident; the duration of contact between water and iron being controlled with the greatest precision by simply regulating the rate of flow, thus avoiding either insufficient purification or wasteful use of the purifying material.

(*b*) **By the constant rubbing of the particles of iron against each other,** and against the sides of the cylinder during its rotation, the iron is rendered self-cleansing, new surfaces being continually presented to the water, while the dissolved iron is at once carried out of the cylinder. It may be said that this want of self-cleansing and revivifying power is the great and universal defect of all other systems of chemically acting purifiers and filters. Though many schemes have been devised, with more or less success, for mechanically cleaning filters *from time to time* by reversed currents and other means, none of these ensure that the purifying material shall *at all times* be equally free from the matters arrested by filtration, or produced by chemical action. It is, in fact, to the difficulties resulting from this general defect, and to the recognition of their cause in the case of large spongy iron filters, that the invention of the revolving purifier is due. How completely Mr. Anderson's apparatus does effect the object aimed at, may be readily seen by inspecting the iron in any revolver which has been at work for some months, when the particles of the metal will be found brightly polished, and the cylinder itself entirely free from any deposit of rust or scale.

(*c*) By the use of metallic iron in the revolving purifier **all colour is removed** from ordinary waters suitable for potable supply, and which the slowest practicable filtration through sand is powerless to render clear and bright. After a short contact with iron followed by a rapid sand filtration, such waters become perfectly colourless and

limpid, even when examined through a depth of several feet. This result is frequently of very great advantage, especially in the numerous cases where the source of supply, otherwise unexceptionable, is liable at times to acquire a yellow, brown, or opalescent appearance from contact with peaty or clayey soils. Such colour, though it may not indicate any harmful quality of the water, tends to lower its commercial value for town supplies. The water of the river Nethe, from which the city of Antwerp is supplied, is at times so strongly coloured by peaty matters, that twenty thicknesses of fine filter-paper fail to remove its opalescent appearance. Four minutes' contact with iron in the "revolver," followed by a rapid sand filtration, renders this water as clear and bright as deep-well water. The same remarkable effect is produced at Gouda and at Dordrecht, in Holland, where the sources of supply are much discoloured at certain times of the year.

The waters of the Nile also exhibit, in a remarkable manner, the powerful effects of iron. The mud carried down by the great river of Egypt is in so fine a state of subdivision that it cannot be separated by filtration at any practicable rate, and it will not subside in any reasonable time, yet after treatment with iron in a revolving purifier it filters rapidly through a thin layer of sand and becomes brilliantly clear.

(*d*) **The very low cost** of purifying water in large volumes by means of Anderson's Revolving Purifier, places this invention far in advance of any other purifying process in this respect.

Firstly.—The capital outlay necessary to apply the apparatus to large waterworks where sand filters already exist, may be estimated at 1000*l.* per million gallons purified daily.

Where sand filters do not already exist, the calculation of the further capital outlay they would involve, may be based upon a rate of filtration of 80 gallons per square foot of filtering surface per 24 hours. For a quantity of one million gallons per 24 hours, this means

$\frac{1,000,000}{80} = 12,500$ square feet of filtering surface. Add one-fourth of this area to allow for part of the filters being always laid off for cleaning, and we have 15,625 square feet as the total area required per million gallons filtered daily. At two shillings and sixpence per square foot, this gives us a first cost of slightly under 2000*l.* Hence the total capital outlay for purifying and filtering one million gallons per 24 hours will be 3000*l.* The exact cost of sand filters will of course vary according to the soil in which they are constructed, the cost of materials and other local conditions, but the above figures may be considered a fair average estimate, especially when it is borne in mind that, after treatment of water by iron, a filter may be worked with a depth of only 2 feet, or even less, of sand, so that a very shallow filter-basin is required. In cases where it is sought to remove colour from water by mere mechanical sand filtration, the rate has to be limited to a maximum of 40 gallons per square foot per day. In such cases, therefore, it will be seen that 31,250 square feet of sand surface, costing 4000*l.*, would be necessary to produce a result which the combination of revolving purifiers and shallow sand filters will effect far more efficiently, while involving a capital outlay 25 per cent. smaller.

Secondly.—The working cost of purification by iron in the revolving purifier either used alone or in conjunction with sand filtration, is so exceedingly low as to leave this system of water purification without a rival among the numerous processes applicable to large volumes of water.

The expenses incurred in passing the water through a purifier or a battery of purifiers consist in the value of the iron used in the apparatus, in the motive power and lubrication, and in the manual labour required for periodically adding fresh iron, and for maintaining the purifier and its motor in working order. Sand filtration following purification involves, as in other cases, the occasional

cleaning of the sand surface by the removal, washing, and replacing of a layer of sand about half an inch thick.

Actual experience at the Antwerp Waterworks, where the whole of the water supply has for the last three years been passed through revolving purifiers, and subsequently filtered through sand, gives the following as the working cost per million gallons calculated upon an average of 1,650,000 gallons of water purified and filtered per twenty-four hours.

WORKING COST PER 1,000,000 GALLONS PURIFIED AND FILTERED THROUGH SAND.

	Shillings
(*a*) *Purification only*:—	
Iron (100 lbs. of C. I. borings at 32*s*. per ton) ..	1·43
Driving-power, oil, &c.	1·00
Labour on Purifiers and supervision	1·57
TOTAL	4·00
(*b*) *Aëration and sand filtration*:—	
Cleaning aërating trough	0·33
Filter-cleaning	9·49
Pure water for sand-washing (10,000 gallons at 2½*d*. per 1000)	2·08
Supervision	2·00
TOTAL	13·90

Total working cost (*a*) and (*b*) per million, say 18 shillings

It will be noticed from the above how small a proportion of the total working cost is due to the purifiers themselves. The cost of filter-cleaning at the Antwerp Waterworks is very high, partly from the nature of the water, and partly on account of the works not having been designed from the outset for the revolving system of purification.

The insoluble ferric oxide (Fe_2O_3) in its formation creates a precipitate of considerable consistency. The water on leaving the revolving purifiers should therefore be first received into subsiding reservoirs of sufficient capacity to

allow of this and of the coarser portions of the precipitate falling to the bottom. The sand filters should then receive the water from the surface by decantation, so that they would have only to arrest the very fine grains of the ferric oxide, which, on account of its lightness, requires in some cases a long period for subsidence. At the Antwerp Pumping Station the subsiding reservoirs serve principally for holding the river water before treatment, the whole day's supply having, by law, to be taken in rapidly at a fixed state of the tide. No means have been provided for the subsidence of the precipitated iron and of the suspended matters before filtration, and the whole of these are deposited on the surface of the sand. As a consequence it is necessary to clean the top of these filters every fifteen days on the average. At Dordrecht, in Holland, where a revolving purifier has also been applied to existing works, but where the river water contains much less suspended matter, filter-cleaning is necessary at intervals of three months only; while, at Gouda, in the same country, where subsiding reservoirs are placed *between* the purifier and the sand filters, the latter maintain their permeability still longer. It may safely be asserted that on works designed specially for the iron purification process the cost of filter-cleaning would not exceed 5*s*. per million gallons and the total working cost would be under 13*s*. per million.

III.—MODE OF ERECTION. DRIVING POWER.

When erecting a Revolving Purifier care must be taken to raise both the inlet and outlet pipes to such a level as will prevent the cylinder from even partially emptying itself and admitting air.

In cases where the outlet pipe delivers direct into a sand filter or into a trough, the end of the outlet pipe should be 2 or 3 inches above the top of the cylinder. In other cases a small tank should be fixed on the vertical outlet pipe, as in Plate III.; the bottom of the tank not

being lower than the top of the cylinder. From this tank will start a separate pipe conveying the water to a sand filter or elsewhere. When pumping direct through the purifier care must be taken not to pump air into the cylinder with the water.* When there is any fear of this happening, the water should be received in a small tank to which the inlet pipe of the apparatus is connected at a level sufficiently high to keep the cylinder always full of water. The most suitable levels for fixing the inlet and outlet pipes or tanks will vary according to circumstances, but their relative positions must be such as will allow of a few inches of head for the flow of water through the apparatus.

For producing the very small power required for the rotation of the cylinder various motors may be used:—

Plate II. represents a battery of five revolving purifiers, as erected at the pumping station of the Antwerp Waterworks at Waelhem, near Malines, Belgium. This group of apparatus is contained in a building 43 feet long by 31 feet wide, and is capable of purifying in the aggregate up to nearly 4 million gallons of fairly good water per twenty-four hours. In this case the revolvers are driven, either together or separately, by belts off pulleys on a horizontal shafting carried by brackets on the wall of the house. At each end of the shafting is a 6-horsepower wall steam-engine—either engine being powerful enough to drive all five purifiers and an air-blower, the other being kept as a stand-by. The purified water is delivered into an outlet tank common to all, and which communicates with the sand filters by means of a long open trough, which forms a continuation of the outlet tank inside the house.

Plate III. shows a very convenient driving arrangement adopted for the revolving purifiers erected at the waterworks of the towns of Dordrecht and Gouda, in Holland. In this arrangement the river water is pumped, after settlement, direct into a small circular inlet tank, whence it

* Vide page 70.

being lower than the top of the cylinder. From this tank will start a separate pipe conveying the water to a sand filter or elsewhere. When pumping direct through the purifier care must be taken not to pump air into the cylinder with the water.* When there is any fear of this happening, the water should be received in a small tank to which the inlet pipe of the apparatus is connected at a level sufficiently high to keep the cylinder always full of water. The most suitable levels for fixing the inlet and outlet pipes or tanks will vary according to circumstances, but their relative positions must be such as will allow of a few inches of head for the flow of water through the apparatus.

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flows through the apparatus to the outlet tank, the delivery pipe from which supplies a reaction wheel, which turns the revolver through a train of gearing.

Plate IV. shows a $1\frac{1}{2}$-inch "revolver" adapted for the supply of a factory or other establishment where large quantities of pure drinkable water are required. An arrangement similar to that illustrated is in constant operation at the ironworks of the Société anonyme des Anciens Établissements Cail at Paris, where the water, drawn from the Seine at a point below the city, is purified and supplied for drinking and domestic purposes to some thirty families connected with the staff of the works. In this case the purifier is fixed on the top of a reservoir, placed at the highest point of the building, and serving also as a sand filter. Movement is given to the cylinder by a belt off the main shafting of one of the machinery shops, no special motor or pump being necessary in this instance.

Various other methods of application will readily suggest themselves to suit particular cases. One great recommendation of the revolving purifier is its easy adaptability to all of the numerous cases where sand filters already exist, or where there are tanks which for little more than the cost of the sand may be made to serve the double purpose of sand filters and storage reservoirs.

IV.—FORMS OF IRON. REGULATION OF CONTACT.

From experiments made previously to the adoption of Anderson's Revolving Purifier for the purification of the Antwerp water supply, it was found that the rate at which iron was dissolved by ordinary river water was only $\frac{1}{10}$th grain per gallon, Bischof's spongy iron being the form of iron experimented on. In actual practice at Antwerp, cast-iron borings have been mostly used, spongy iron being less suitable for the purpose, on account of the irregularities of its surfaces, and its much greater first

cost. Cast-iron borings have, however, the disadvantage of being very friable and easily knocked to pieces, so that in addition to the waste of iron due to chemical action, there is a still greater loss from the carrying-away of the pulverised metal by the flow of water. The most convenient and economical forms of iron for use in revolving purifiers are "granulated iron," cast-iron balls, and small "burrs" from punching-machines. As far as present experience shows, the last three forms lose about the same weight per gallon of water purified. This loss may be taken at an average of $\frac{1}{5}$ grain per gallon, as against $\frac{3}{8}$ grain when cast-iron borings are used. Cast-iron borings may, however, frequently be had at $\frac{1}{3}$ of the cost of either of the less friable forms of the metal, so that the material so used should be the one most easily available in the particular locality. Should either of the harder forms be chosen, care must be taken that their particles are not so large and heavy as to injure the cylinder. A good rule is that all the iron shall pass through a sieve of $\frac{3}{8}$-inch mesh, when required for use in sizes of apparatus up to 6 inches, and through a $\frac{1}{2}$-inch mesh for larger sizes.

Where only one "revolver" is used, the **regulation of the duration of contact** between iron and water is very simply effected by means of a regulating weir or sluice, when the water flows direct from the source of supply, or by the speed of the pump used for raising the water where this is necessary.

Where two or more apparatus work simultaneously, it is desirable to lay down certain rules to prevent the possibility of the water flowing through any one purifier more rapidly than through another, and so being imperfectly purified. The five revolvers forming the purifying plant at Antwerp are supplied by two of Airy's screw pumps, which raise the water from the storage reservoirs into small tanks. These tanks communicate with the inlets of the purifiers by a cast-iron pipe of sufficient diameter to reduce loss of head by friction to a minimum, and pre-

vent any sensible variation in the quantity of water each apparatus receives. Screw pumps have the advantage of running very slowly, and of delivering exactly the same quantity of water per revolution at whatever speed they may be working; they consequently form excellent meters, and are particularly well suited for use with a battery of purifiers. At Antwerp each screw pump raises 55 gallons per revolution, with a loss of 2 or 3 per cent. due to leakage and overflowing; a rule is laid down that for every 6 or 8 revolutions of a pump per minute—according as a contact with the iron of 5 or $3\frac{3}{4}$ minutes is found desirable—one revolver shall be put in action. Centrifugal pumps are not to be recommended for supplying the water to a group of purifiers on account of the difficulty of varying and regulating their delivery as required.

V.—THEORY OF THE IRON PROCESS. AËRATION AND FILTRATION.

As far as scientific researches have at present been able to settle the question, the **action of the iron in Anderson's Revolving Purifier** is one of reduction, to be followed, on the water leaving the apparatus, by one of oxidation. The carbonic acid contained in the impure water acts upon the metal, forming carbonate of iron. On being exposed to the air, the ferrous salt is oxidised, and converted into the insoluble ferric oxide (Fe_2O_3), the carbonic acid being liberated, and escaping in the form of gas. From this it will be seen that proper **aëration after purification** is indispensable to complete the process. It is found that in most cases four hours' exposure to the air is ample to completely precipitate all the dissolved iron, which is then easily removed from the water by a rapid mechanical filtration, no trace of iron remaining in the purified and filtered water. To effect this aëration in the most efficient way on the large scale—as in the case of waterworks for the supply of towns—it is advantageous to place the purifiers as near to the source of supply and as

far away as possible from the sand filters. When practicable, the purified water, on leaving the purifier, should be made to flow slowly along an open trough or channel into settling ponds, whence it can be decanted on to a sand filter after a few hours' subsidence. Where the level will allow of it, further beneficial aëration may be obtained by letting the water fall in a cascade on leaving the purifiers. In cases where the raw material is of exceptionally bad quality, or has a taste or smell, excellent results may be obtained by blowing air into the water by artificial means. In some cases, also, where the water is not of such bad quality, artificial aëration has been found desirable, the oxides of iron refusing to precipitate completely without it. With most moderately good waters, aëration in an open trough or in the sand filters alone is sufficient.

The arrangement adopted for artificial aëration at the Antwerp Waterworks is represented on Plate II., Fig. 1. A 3-inch iron pipe runs along the whole length of the outlet tank which is common to all the purifiers. A $1\frac{1}{2}$-inch branch, provided with a plug cock, descends from this pipe over each of the vertical outlets, into which it enters to a depth of some 18 inches below the mean water level in the tank. The lower end of each branch terminates in a circular plate 5 inches in diameter, leaving an annular space $2\frac{1}{2}$ inches in width, through which the outflowing water and air pass together into the tank. A second mechanical aëration is provided by means of a 6-inch pipe, Figs. 2 and 3, which conveys air from the blower under a series of sheets of finely perforated zinc, arranged to form a false bottom to the first portion of the open trough along which the purified water flows on to the sand filters. Through this false bottom countless small bubbles of air rise and mix with the water. The water then flows along the open channel and enters each of the six sand filters through a regulating weir, falling on to a series of steps on which coke is placed. The coke is found to greatly aid the oxidation of the dissolved iron, both by breaking up the stream of water and probably also by the action of the

oxygen condensed on its surfaces. The supply of air forced into the water at the outlet of the purifiers is obtained by means of a small Roots blower in summer, and by one of Körting's steam injectors in winter.

Sand filters should be composed of a bed of clean river sand from 1 foot 8 inches to 2 feet in thickness, overlying a layer of washed gravel sufficiently fine at the top to prevent the grains of sand from being drawn down into it, and from 6 inches to 1 foot in thickness.

The speed of filtration to be adopted depends upon several considerations, varying with particular cases, such as the quantity of suspended matter, other than iron, in the water, the facility with which the ferric oxide is formed, and the means of aëration available before filtration. A safe figure, however, upon which to base calculations in estimating filtering power is 80 gallons per square foot of sand-surface per twenty-four hours. When the iron precipitates readily and in large flakes, as much as 150 gallons per square foot would be admissible; but this is an excessive speed for true economy in working filters, as the finer particles of the suspended matter are drawn down deeper into the filter, and more sand must be removed and washed at each cleaning. It should be observed that 80 gallons per square foot is already about twice the maximum speed generally permitted in ordinary sand filtration. In cases, therefore, where it has become desirable to extend existing filters, to keep pace with growing demands, capital outlay may be saved by adopting revolving purifiers, as the existing filter area may thus be made to do double the work. As an instance the town of Dordrecht, in Holland, by erecting a "revolver" has been enabled to deliver double the quantity of water to its consumers at a cost of only $\frac{1}{8}$th of the sum estimated as necessary for doubling the area of its filter beds. At the same time the increased supply is of greatly improved quality (*vide* Part II. Chap. IV.).

Where the iron purification process is adopted, the **method of cleaning the sand filters** differs notably in one

important respect from the plan now generally recognised as the best in the case of ordinary sand filtration.

Through the action of the iron oxides, the reduction of the organic matter may be said to be completed by the time the water reaches the top of the sand. The filter retains at its surface the objectionable ingredients of the water enclosed in and precipitated with the flakes of ferric oxide. The body of the filter is thus never rendered foul by putrescent matters, as is the case when it is sought to render potable an impure water by sand filtration alone. In the latter case, in order to avoid the danger of using a foul filter, it is the general practice to fully aërate the whole mass of the sand by periodically turning it over. When the water has been previously treated with iron, not only is this disturbance of the sand not necessary, but it is proved beyond a doubt at Antwerp and elsewhere that the sand filters improve by being left alone, and are less efficient after being opened up. Not only does age render the filter-bed more homogeneous and efficient as a strainer, but it is found that a portion of the iron salts permeate the sand layer until, after lengthened use, each grain of sand is coated with a red film of iron oxide. This coating is insoluble in water, and firmly adherent to each grain it encloses, no colour being given off in washing any portion of the sand taken from a few inches below the surface. Thus impregnated through their mass as well as coated at their surface with the iron oxide, sand filters that have been for some time working in conjunction with "revolvers," are found to possess, to an extraordinary extent, the power of absorbing and retaining free ammonia. It has been objected that this power of absorption must eventually become exhausted, and that the filter must end by again yielding up the ammonia. Whether in the long run these objections will be justified or not, the fact remains that at the present moment, after three years' constant and undisturbed working of the filter-beds, the filtered water at Antwerp, tested by Wanklyn's delicate method of analysis, contains no measurable quantity of free ammonia at all.

It would probably be impossible to find such complete absence of free ammonia in the purest spring or deep-well waters. As pointed out by Professor Kemna, in his report on the Ostend experiments of 1886, the water of the Vanne, the ideal of pure spring waters, and which forms part of the Paris supply, contains more free ammonia than is found in a sample drawn from a tap on the high-pressure service of the city of Antwerp. Neither is the ammonia present in its oxidised forms, both nitric and nitrous acid being reduced to the faintest trace in the Antwerp water.

The method now followed in cleaning the sand filters at Antwerp is as follows:—A filter is allowed to drain itself as nearly down to the surface of the sand as it will within a reasonable time, the supply to it being generally shut off in the evening, and the filter ready for cleaning in the morning, when some 4 or 5 inches of water will still be found overlying the firm deposit on the surface of the sand.

The delivery valve of the filter is then closed, the sides of the filter basin are washed down, and the dirty water on the top of the sand is drawn off through a pipe passing through the filter bank at the level of the sand surface. The thin deposit covering the bed of sand is next carefully removed by shovels, a depth of about half an inch of sand being taken up with it and sent up to the sand washing tanks in barrows.

When, after successive cleanings, the thickness of the sand layer has been reduced by some six inches, washed sand is replaced, being evenly spread over the whole surface and rolled smooth. In refilling, clean water from a neighbouring filter is admitted from below, the first portion rising above the sand being thrown away through the flushing pipe. This plan ensures that none of the turbid water from the top is drawn down into the sand.

It would probably be found possible to avoid altogether the removal of the top layer by shovels, by gently sweeping off the iron deposit through the flushing pipe, were the heavier solid and precipitated impurities retained in a settling tank, instead of being collected on the top of the sand as is the case at Antwerp at present.

VI.—DIMENSIONS OF APPARATUS.

Anderson's Patent Revolving Purifier is made in fourteen sizes, which are denominated according to the diameter of their respective inlet and outlet pipes. In determining the size of purifier required for a given number of gallons of water per day, calculations must be based upon the duration of contact with the iron found necessary by previous experiment for the most complete purification of the particular water. For ordinary river water capable of being rendered fit for a potable supply, it may be said generally that this duration of contact must never be less than $3\frac{1}{2}$ minutes, and need be seldom more than 5 minutes. Excessive contact causes more iron to be dissolved than can easily be precipitated, without producing a proportional improvement in the water. With less than $3\frac{1}{2}$ minutes' contact it is difficult to ensure regular or sufficient purification.

In the following table the capacity of the purifier is given in gallons, allowance having been made for the space occupied by the iron. The maximum quantities of water that can be purified per 24 hours, with contact between iron and water of $3\frac{1}{2}$ and 5 minutes, are also given.

To determine the delivery of a purifier per 24 hours when allowing any other duration of contact, it is sufficient to divide the number of gallons contained in the purifier by the number of minutes' contact required, and to multiply the result by 1440. Or, inversely, to determine the size of purifier required for a given number of gallons per day with a given number of minutes' contact, divide the total 24 hours' requirements by 1440, and multiply by the number of minutes of contact.

It will be noticed what large volumes of water may be purified by a single apparatus, a 14-inch purifier being capable of treating over $1\frac{1}{4}$ million gallons per day with $3\frac{1}{2}$ minutes' contact, and occupying a space of 34 feet by

10 feet only. At the Dordrecht Waterworks a purifier of this size has been erected, and is at work for several hours daily, at a delivery of 880 gallons per minute, the duration of contact with the iron being a fraction under 4 minutes. It not unfrequently happens that the water to be purified varies in quality at different seasons of the year, and requires corresponding variations in the duration of its contact with the iron. In this case, of course, the purifier selected must be of sufficient size to give the longest contact likely to be necessary under the most unfavourable circumstances.

The fifth column of the table gives the **area of sand filters required** to correspond with a purifier when working with 3½ minutes' contact, and calculated for a rate of 80 gallons of water filtered per square foot per 24 hours. Should the purifier be given a longer contact, the rate of filtration will be proportionately reduced. With very bad waters, however, unless arrangements are made for the subsidence of the heaviest portion of the precipitate before filtration, it might be necessary in some cases not to reduce the areas of sand surface below the figures given, even when the purifier is delivering the smaller quantity with the increased duration of contact. Where an efficient subsiding reservoir is placed between the purifier and the sand-filter, the rate of filtration may, in many cases, be increased beyond 80 gallons, and the area of the sand filters reduced accordingly.

The sixth column shows the **weights of the initial charges of iron** introduced into each purifier when first set to work. It is not found necessary at Antwerp ever to remove and renew the whole of the iron with which the apparatus is charged. It is sufficient to maintain the weight of the initial charge by the periodical addition of so much of the metal as is necessary to compensate for the loss due to the chemical action and the mechanical washing away of the particles of iron by the water. The frequency of the periods at which to add fresh iron will vary according to the quantity of water passed

Dimensions and Deliveries of Revolving Purifiers.

Size of Inlet Pipe.	Capacity of Cylinder.	Delivery in Gallons per 24 Hours.		Area of Sand Filters required at 80 Gallons per Square Foot per 24 Hours.	Weight of Initial Charge of Iron.	Driving Power in Foot-pounds per Minute.	Floor Space occupied by Complete Apparatus.
		3½ Minutes' Contact.	5 Minutes' Contact.				
inches.	gallons.			square feet.	lbs.		ft. in. ft. in.
1	15	6,170	4,320	80	28	690	5 6 × 1 8
1½	31	12,700	8,890	160	60	880	7 0 × 2 0
2	61	25,180	17,620	320	97	1,380	8 0 × 3 5
2½	96	39,490	27,640	500	153	1,800	10 0 × 3 5
3	138	56,770	39,740	720	224	2,500	10 0 × 5 4
4	246	101,210	70,840	1,270	392	4,130	11 0 × 5 9
5	381	156,750	109,720	1,970	616	5,630	14 6 × 5 9
6	576	236,980	165,880	2,965	896	5,880	15 6 × 7 6
7	771	317,200	222,040	3,965	1,187	7,440	19 0 × 7 6
8	978	402,370	281,660	5,040	1,568	9,880	19 0 × 8 0
9	1,287	529,500	370,650	6,620	1,971	12,000	22 0 × 8 0
10	1,689	694,900	486,430	8,690	2,464	15,000	23 6 × 3 0
12	2,319	954,100	667,870	11,930	3,584	20,630	30 0 × 8 6
14	3,126	1,286,120	900,280	16,090	4,704	28,500	34 0 × 10 0

through the apparatus and the rate of waste. Generally speaking, the iron should be brought up to its original weight once a week.

The seventh column of the table gives the **amount of driving power** required for each purifier in foot-lbs. per minute, from which the horse power of the motor required can be calculated.

The last column shows the **floor space** covered by each complete apparatus.

In designing an arrangement of revolving purifiers for large volumes of water or sewage, where the machinery will be constantly at work, or nearly so, it is advisable to allow for duplicating the plant by selecting two apparatus of smaller size, each capable of treating say five-eighths of the day's supply, rather than a single purifier to do the whole work alone. Where pumping is intermittent, or where it is convenient to reduce its amount during some part of the twenty-four hours, this duplication is particularly convenient, one apparatus being temporarily stopped. At the Antwerp Waterworks there are, as already stated, five 10-inch purifiers. These correspond approximately to five sand-filters, a sixth filter being always laid off for cleaning.

PART II.

ANALYTICAL RESULTS AND REPORTS.

In addition to the apparatus first made use of by the Antwerp Waterworks Company in the early part of 1885, after protracted experiments on a smaller scale during the previous year, Anderson's Patent Revolving Purifiers are now in full work at the Dordrecht (Holland) Municipal Waterworks; at the pumping station of the Gouda Waterworks Company; at the ironworks of "La Société des Anciens Établissements Cail," in Paris; and at the great brewery of Messrs. Tourtel Frères, near Nancy, France. Experiments on a large scale have also been made for extended periods at the Lea Bridge Works of the East London Water Company, at Berlin, and at Ostend.

In all these cases most successful results have been obtained, except at Berlin, where, during certain conditions of the river Spree, a reaction appeared to take place after purification, a portion of the ferric oxide (Fe_2O_3) being redissolved and passing through the sand filter in a soluble state. In this case, however, a perfectly limpid water was obtained on many days of the trial and it is probable that, with special means of mechanical aëration, all difficulties would have finally been overcome. Besides the above, a very large number of laboratory experiments have been made on waters from various sources.

From the results of something like 200 analyses made by Sir Frederick Abel, Drs. Frankland and Tidy, and Mr. G. H. Ogston, in England; by M. Marié-Davy, Director of the Observatory of Montsouris, at Paris; by Professors Swarts, Blas, Angenot, Kemna, and Jorissen, Dr. Van Melckebeke, and M. Van de Velde, in Belgium; by Drs. Van Hamel-Roos and Dupont, and Messrs. Van de Ven and Giltay in Holland, and by other eminent chemists, it is proved that by the process of purification

by iron, in the revolving purifier, the organic matter is reduced from 45 to 85 per cent., according as its origin is principally vegetable or animal; the albumenoid ammonia from 50 to 90 per cent., and that the free ammonia present in the unpurified water is completely eliminated; at the same time all colour originally present in the waters experimented upon is, except in rare cases, entirely removed after a contact with metallic iron of from 3¼ to 5 minutes' duration, followed by a rapid filtration through sand, although, in the great majority of cases, the slowest practicable filtration through sand, when not preceded by agitation with iron, failed to render the water perfectly bright and colourless.

I. MR. OGSTON'S EXPERIMENTS.

Mr. G. H. Ogston, F.C.S., was the first chemist to experiment with Mr. Anderson's process. He published the results of his experiments in a communication made to the Institution of Civil Engineers in 1884, and entitled "The Purification of Water by Metallic Iron in Mr. Anderson's Revolving Purifiers" (Minutes of Proceedings Inst. Civ. Engineers, vol. lxxxi. part iii.)

To those readers who cannot easily refer to this publication, the following extracts will be interesting:—

"The experiments now to be mentioned have all been made in the author's laboratory with a model apparatus constructed by Mr. Anderson, and used in every way as the large forms would be used; with the same rate of flow and the same quantity of iron in relation to the water to be purified; differing only in that the experiments were necessarily interrupted from day to day, instead of being continuous, as in practical works they would be. The capacity of the model revolver is 3½ lbs.; and this quantity of water passes through in from three to five minutes. It has not up to this time been possible to examine a large number of waters, but those that have been dealt with present a considerable variety of composition, and are probably fairly

representative of waters commonly met with. The first obvious effect of the iron upon impure water is to deprive it of any colour it may have. A minute quantity of this iron is immediately dissolved, probably as ferrous carbonate, and almost immediately thrown down as ferrous oxide. After a short exposure this becomes ferric oxide, which is deposited and separated with great ease by filtration through a very shallow layer of sand. . . . The effect of this treatment upon the waters that have been examined is to deprive them entirely, as seen through a tube 2 feet long, of the colour due to dissolved organic matter; and the removal of this matter is accompanied by the breaking up of certain nitrogenous compounds as shown in the analytical results, by a great reduction in the amount of the albumenoid ammonia.

"The following table shows the amount of albumenoid ammonia, in a million parts, in several waters that have been analysed, and includes samples varying greatly in composition and in the original quantity of the organic nitrogen."

	Before Purification in Revolver.	After Purification in Revolver.
Water from Zurich	0·020	0·010
" " Ostende	0·140	0·080
" " Laeken	0·185	0·060
" " Thames	0·150	0·060
" " Malines	0·260	0·060
" " Antwerp	0·200	0·080
" " Northwich	0·110	0·040
" " Itchen	0·080	0·040
" " New River	0·030	0·015
" " Hertford Sewage	0·330	0·080

The writer then proceeds to describe the experiments made by him with a view of testing the destructive effect of metallic iron, when used in a revolving purifier, upon the germs of bacterial life. This destructive effect of iron, when used in the form of "spongy iron," had already been proved by the investigations of Dr. Frankland, the late Mr. Hatton, and by Professor Bischof, the inventor of this special form of the metal. Mr. Ogston says,—

"The experiments made by the author upon waters after being in contact with metallic iron, lead him strongly to the belief that this treatment completely destroys the microbes.

In most of the experiments this water, after passing through the revolver, was incapable of setting up fermentation in either hay effusion or meat extract, although occasional failures occurred, especially at first." . . .

"The waters upon which most of the experiments have been made, to which the author desires to draw attention, have been: Water from the Thames as being easily obtainable, and water from Laeken (Belgium), an impure water of which the author had a quantity at his disposal. In the case of the Thames water, five experiments out of seven, in which it was passed through the revolver, were successful, the water being completely sterilized, whilst two failed. In the Laeken water, which is taken from a stream supplying the lake in the Park of his Majesty the King of the Belgians, three experiments succeeded and one failed. With the Zurich water, remarkable as being almost free from organic matter, and supposed to have occasioned much disease, the only experiment made showed that in its original condition it rapidly developed bacteria in the meat-extract; but that it was completely sterilized after purification. With water from Northwich, in two experiments the sterilizing effect was produced, and in one case it failed. Throughout the trials, in about four cases out of five the mode of treating the water that has been described has completely sterilized them. It must be understood that in every case the water not so treated was active in determining the decomposition of the meat-extracts under similar circumstances and that comparative tests were always made with the samples in the two conditions side by side." . . .

"It seems that if, in the great majority of cases, the organisms are destroyed the effectiveness of the agent is established, since it is not at all likely to be capricious in its action. Considering these facts, and considering also the great reduction effected in organic nitrogen, and the removal of colour from impure waters, there appears to be reason for the belief that an economical and efficient method of water purification has been found in the mode of treating by metallic iron; indeed it would seem that impure waters purified by means of iron will prove safer for dietetic purposes than even good deep well or spring water, because after treatment water can be preserved from contamination by means of covered reservoirs, or in mains and pipes,

whereas wells and springs, as numerous cases prove, may become dangerously contaminated.

"The only specimen of true sewage the author has been able at present to deal with in this way is that from Hertford, taken from the Manifold ditch below the town. The result of experiments with this liquid, so far as they were carried out, was very satisfactory. The albumenoid ammonia was always reduced to 0·08 in a million parts, and of the two experiments that were able to be made with it, after purification, one was completely successful in destroying all organisms. The second experiment, which exhausted the supply of sewage, failed from an accident to the apparatus."

II.—THE ANTWERP WATERWORKS.

The adoption of Anderson's purifiers at the pumping station of the **Antwerp Waterworks**, and the conversion of the original "spongy iron" filters, to suit the new process, took place in the early part of 1885. At this time three purifiers only were erected, it being estimated that their maximum delivery would be sufficient to meet the requirements of the city. The opening of the International Exhibition, however, and a drought lasting throughout the summer, taxed the water company's installations beyond their powers. The result was, that during some weeks in August and September the river-water had to be passed through the purifiers at a speed which gave too short a contact with the iron for complete purification. The water supplied to the city was considered to be of inferior quality, and complaints were made of its taste and smell. The authorities therefore appointed a commission, consisting of five well-known Belgian chemists, to report upon the water supply. These gentlemen published in November, 1885, a very exhaustive report, which concludes as follows :—

"It results, from the work of this commission, that the water supplied by the Waterworks Company during the months of August and the beginning of September, 1885, has left something to be desired from the chemical point of view,

and its "organoleptic" properties (taste and smell) rendered it unsuitable for most domestic uses. The commission must, therefore, declare the complaints of the public both well-founded and legitimate; but it cannot share in the exaggerated fears which have been expressed. Nothing, in fact, allows it to be considered that this water has ever been insalubrious or as having placed the public health in danger.

"The cause of this temporary state of things has been a consumption suddenly increased far beyond the largest expectations, and allowing the company no other alternatives than those of either seeing its installations dried up or of effecting a hasty and insufficient filtration. At the same time, a raw material, more concentrated by the prolonged drought, rendered purification more difficult. The doubts which might have been conceived of the efficiency of the process (of purification) fall to the ground before the re-researches of the commission, which confirm those of the English scientists. It will be sufficient for the Waterworks Company to increase its installations, and to modify, in a few points, its operations in the way indicated above, to allow of its ensuring always what it now is supplying, an irreproachable drinking water."

The report also says, after describing the former system of "spongy iron" filters:—

"The commission recognises that the Anderson purifiers constitute a great step in advance over the filtering basins. Well handled, they appear of at least equal efficiency; they are much more economical; they are more scientific in character, in that they allow of proportioning the duration of contact to the degree of impurity of the water."

The commission also made microbiological examination of the water, with a view to determine the influence of the process in the destruction of bacterial life. Samples of water drawn from a tap in the city were submitted to a series of tests, from which the following conclusions were drawn:—

"The water of the supply, while not being exempt from microbes, contains only a very small quantity of them, and far less than one generally finds in the majority of natural waters."

The addition of two more 10-inch purifiers, an open canal between the purifiers and the sand filters, and mechanical means for better aërating the water on its leaving the purifiers, has enabled the Antwerp Water Company to maintain a constant supply of hygienically pure water since 1885. During a few days only in 1886 and 1887 was there a slight return of the marshy taste complained of in 1885. This taste, whose cause has long puzzled the Company, is now ascribed to the growth of a "spongilla" in the pipe bringing the unpurified water to the purifiers. This substance, whose growth in the hot weather is very rapid, becomes detached in small pieces from the sides of the pipe, and is carried by the water through the revolvers and on to the filter beds, where, when sufficient of it has collected, the purified water takes up again the taste which it had lost in the aërating trough. Steps are now being taken to prevent the growth of this substance, and it may confidently be hoped that the re-appearance of the marshy taste will be effectually prevented in the future.

These remarks on the Antwerp water supply may be supplemented by the following extracts, translated from a report made to the Company in May 1887 by Professor Blas, of the University of Louvain, and Dr. Jorissen, of the University of Liége, who were invited to make a joint analysis of (1) the river water taken from the subsiding reservoirs before purification; (2) the purified water as it left the purifiers at the pumping station; (3) a mixture of samples drawn from several of the public standposts of the city. On these samples the analysts report as follows:—

"Water No. 1 is thick, coloured; it exhales a disagreeable smell and leaves an abundant brown deposit. Taking these

properties in conjunction with the results of chemical analysis, we conclude that this water is not potable.

"Water No. 2 is limpid, colourless, without either disagreeable taste or smell; it does not deposit, and is not spoiled by keeping. Taking these qualities in conjunction with the results of the chemical analysis we consider this water as potable and of good quality.

"As to sample No. 3, it is identically like sample No. 2.

"In comparing the results furnished by the analysis of the samples 1, 2, and 3, it is seen that the process of purification applied by the Waterworks Company, whose installation we have visited in detail, has the effect of depriving the water of the Nethe of the matter it holds in suspension, of causing the complete disappearance of the ammonia and nitrous acid, and of reducing by 50 per cent. the proportion of organic matter found in this water before purification. . . . We consequently conclude that the process of purification applied at Waelhem at the time of our visit produced good results, and that the water of the supply of the city of Antwerp, analysed by us, may be considered to be a potable water of good quality."

The antiseptic properties of water treated by iron are demonstrated in a practical way by the Antwerp supply. The writer has in his office several samples of water drawn from the mains in 1886, which at the present time are unaltered in appearance and taste, and show no signs of that vegetable growth which few waters are long exempt from if preserved in glass bottles under ordinary conditions. Further, the captains of the Red Star Liners, running between Antwerp and New York, make a rule of keeping a tank of the water taken in at Antwerp in reserve for the return journey, finding it more palatable after being stored for some three weeks than water they could take in fresh elsewhere.

The general arrangement of the works at the Waelham Pumping Station is shown on Plate V. As at present arranged the three large reservoirs Nos. 1, 2, and 3, are used solely for storing the river water which has to be taken in rapidly

at a certain state of the tide, and for allowing for the subsidence of the heavier matters in suspension in the river water. As already mentioned, the water decanted from these reservoirs is raised by screw pumps and flows through the purifiers along an open channel direct on to the sand filters. It will be obvious then, that the filters receive and have to retain at their surfaces not only the iron precipitates, but also all the dissolved or suspended matter which the purification throws down. This is a defect due to the want of intermediate settling reservoirs. Steps are about to be taken to utilise reservoirs 1 and 2 for the settlement of the purified water, which will then be decanted before filtration. All the heavier substances precipitated being retained in these reservoirs, it may confidently be expected that with this improved method of working, the life of the filters will be very greatly lengthened, and the now heavy cost of filter-cleaning be very considerably reduced.

III.—THE GOUDA WATERWORKS.

The Water Supply of Gouda in Holland, which is drawn from the river Ysel, gave much trouble during several months of the year, on account of the appearance of a deep yellow colour, caused by the contamination of the river by water flowing over peaty soils. Perchloride of iron had been used to remove this colour, and with success as far as appearance was concerned, but the chemical composition of the water was deteriorated by the large increase in the quantity of chlorine, and the cost of this mode of treatment was found very heavy. After several weeks' experiments with a smaller apparatus, a 9-inch Revolving Purifier was erected at the Gouda Pumping Station during the summer of 1886. The revolver was set to work during the following winter, sulphate of alumina being added in minute quantities to the purified water to accelerate the precipitation of the iron oxides, and to bring the so-called "organic" matter down to the figure

fixed by the Company's concession. The cost of foundations being very heavy, the apparatus is placed over the pumps on the first floor of the circular building which serves both for engine-house and water tower. After being pumped up to and passed through the purifier, the water falls again to the level of the engine-room floor, where it drives a reaction wheel, whose vertical spindle actuates in its turn the revolving cylinder. The purified water then flows down an open trough, arranged to form a series of small cascades, into one of two settling tanks, whence, after some hours' subsidence, it is decanted on to the sand filters.

The source of supply at Gouda is typical of the river water on which the majority of towns in Holland are dependent. While bright and excellent in summer, the Ysel becomes turbid and strongly coloured as soon as the rainy season or the melting of snow begins. The water entering the river from the adjacent country flows over and percolates through peaty soil, and renders the river water thick and yellow. After a few hours' settlement the greater part of the turbidity disappears, leaving, in the case of the Ysel, an almost clear liquid of a strong yellow colour. In other cases, as at Antwerp or Dordrecht, where the river or its sources are in a clay country, this comparatively transparent yellowness is replaced by an opalescent aspect amounting frequently to opaqueness, when the water is seen through the standard depth of 2 feet. The most perfect mechanical filtration, at any practical speed, fails to render these waters colourless and bright. Solutions of peat and clay are very powerful decomposers of permanganate of potash, and waters affected by them have generally been regarded with little favour by continental chemists, whose practice has been to found their judgment of the suitability of any source of supply for potable purposes on the milligrammes of permanganate decomposed by a litre of it, considering all the oxidisable ingredients of the sample under analysis to be "organic matter" without distinction as to its animal or

vegetable origin, nor indeed with any certainty of its being "organic" at all. Thus at Gouda the Water Company fulfil the conditions of their concession, and satisfy the sanitary authority, as long as a litre of the water supplied does not reduce more than 15 milligrammes of the reagent. Before the introduction of the revolving purifier, perchloride of iron was used to precipitate the peaty matter, the Ysel water before treatment being at times capable of decomposing as much as 50 milligrammes of the permanganate. Purification by metallic iron alone reduces the oxidisable matter by 55 per cent., brings the ammonia down to its lowest point, and renders the river water perfectly colourless and bright. The standard fixed by the concession is not, however, always reached with 55 per cent. reduction, and recourse is had to sulphate of alumina to obtain the extra 10 per cent. needed. The sulphate of alumina is mixed with the purified water as it leaves the turbine, in quantities varying with the condition of the river, and with it enters the settling tanks, where a complete precipitation of the iron oxides takes place before filtration.

Mr. Becking, the manager of the Gouda Waterworks, has supplied some interesting statistics as to the comparative cost of purification by perchloride of iron alone, and by Mr. Anderson's process, supplemented by sulphate of alumina. Taking it at its worst in both cases, it was found that, to bring the river water down to the required standard, 200 kilogrammes of perchloride of iron were required for each settling tank of 550 cubic metres—as against 150 kilogrammes of sulphate of alumina used in conjunction with the "revolver." The cost of the perchloride was 0·25 franc per kilogramme, that of the sulphate 0·125 franc, the total cost of "chemicals" being respectively 50 francs and 18·75 francs per settling tank treated, or 90 francs and 32 francs per 1000 cubic metres of water purified. To the charge for sulphate of alumina must be added the working cost of the revolving purifier plant as well as interest and amortisation of the capital outlay. These,

liberally calculated, are, respectively, about 5 francs and 8 francs per 1000 cubic metres of water purified. Hence it appears that treatment by perchloride of iron cost 90 francs, while agitation with metallic iron, followed by the addition of sulphate of alumina, cost 45 francs per 1000 cubic metres, or 4*d.* and 2*d.* per 1000 gallons respectively. Were it not for the necessity of attaining the prescribed standard for "organic" matter, sulphate of alumina would be dispensed with, and the total cost of purification would be slightly over ½*d.* per 1000 gallons. An examination of the table of analyses made by Dr. Meymott Tidy, given on the following page, tends to confirm the writer's belief that, in the case of Gouda, the benefits gained in the reduction of the organic matter down to the required standard by the use of sulphate of alumina, are more than counterbalanced by the increase in "total solid matter" in sulphuric acid and in hardness, which are directly traceable to the employment of a "chemical." Mr. Becking bears witness to the satisfactory results obtained without the use of alumina in the following words (Oct. 25th, 1887):—

"For the last three weeks we have got the bad water at our works and are using the purifier. I am glad to tell you it is acting very well, better than last year. The town water is at this moment without colour, clear, and the effect of the purification with sand filtration, and without the solution of alumina, is to produce 55 per cent. improvement (in the organic matter)."

Mr. Becking also states that, purified with metallic iron in combination with sulphate of alumina, the precipitate is completely deposited in 8 hours; while when treated with perchloride of iron from 12 to 15 hours are necessary to produce the same result. He adds that in combination with the purifier, perchloride of iron produces hardly any effect. After settlement, the purified water is filtered through ordinary sand filters to arrest any floating matters that may remain in it, but the precipitation of the iron oxides is so complete that the filters run the whole year without cleaning.

Results of Analyses of Samples of Water from the Antwerp, Dordrecht, and Gouda Waterworks, before and after Purification by Iron, made in April 1887, by Dr. C. Meymott Tidy, Professor of Chemistry and of Forensic Medicine and Public Health at the London Hospital; Medical Officer of Health for Islington; and late Deputy Medical Officer of Health and Public Analyst to the City of London, &c., &c.

The results are stated in grains, per Imperial Gallon of 70,000 Grains; the Organic Carbon and Nitrogen being stated in parts per 100,000.

	Description.	Total solid Matter.	Ammonia.	Nitrogen in Nitrates and Nitrites = Nitric Acid.	Oxygen required to Oxidise the organic Matter.	Organic Carbon.	Organic Nitrogen.	Lime (CaO).	Magnesia (MgO).	Sulphuric Anhydride (SO_3).	Chlorine = Common Salt.	Hardness. Before Boiling.	Hardness. After Boiling.	Silica.	Free Oxygen.	Matters in Suspension. Total.	Matters in Suspension. Mineral.	Matters in Suspension. Organic.
		grains.	grains.	grains = grains.	grains.	part per 100,000.	part per 100,000.	grains.	grains.	grains.	grains. grains.	degrees.	degrees.	grains.	cub. in.	grains.	grains.	grains.
Antwerp Waterworks.	R. Nethe, before treatment	19·80	0·024	0·073 = 0·328	0·112	0·258	0·032	7·59	1·405	1·24	1·584 = 2·596	14·4	2·82	0·38	1·64	4·03	2·34	0·69
	„ after treatment in iron purifier	14·68	0·018	0·052 = 0·234	0·108	0·224	0·030	4·87	1·117	1·24	1·44 = 2·36	9·5	2·82	0·50	0·18	1·24	0·90	0·34
	„ after filtration	12·88	0·006	0·052 = 0·234	0·080	0·180	0·030	4·03	0·864	1·20	1·368 = 2·242	7·9	2·82	0·46	1·38	clear		
Dordrecht Waterworks.	R. Merwede, before treatment ..	17·88	0·003	0·050 = 0·225	0·052	0·160	0·046	5·76	1·225	1·50	1·368 = 2·242	10·9	4·6	0·50	2·14	4·18	3·81	0·67
	„ after complete treatment ..	15·20	0·003	0·050 = 0·225	0·024	0·110	0·040	5·20	1·081	1·67	1·368 = 2·242	9·8	4·2	0·44	1·68	clear		
Gouda. Watwks.	R. Ijsel, before treatment	31·68	0·020	0·062 = 0·279	0·212	0·397	0·050	7·53	2·198	4·82	3·528 = 5·782	17·1	7·7	0·72	1·71	1·24	0·81	0·43
	„ after complete treatment ..	34·44	0·004	0·062 = 0·279	0·084	0·194	0·046	7·95	2·234	10·50	3·672 = 6·018	19·5	11·3	0·80	1·46	clear		

IV. THE DORDRECHT WATERWORKS.

The following extracts, translated from the official Report made in September 1887 by Mr. François, Engineer to the town of Dordrecht, in Holland, and entitled, "Report on the arrangement and working of Anderson's Revolving Purifiers on the premises of the High-Pressure Water Service of the Commune of Dordrecht," show the success which has attended the application of the iron process in this case. The saving of capital outlay effected by the addition of a "revolver" to existing works is strikingly illustrated, and the necessity is shown for mechanical aëration experienced with a certain class of waters:—

"The unexpectedly great popularity enjoyed by the High-Pressure Water Service in this place very soon after its establishment caused the water consumption to be so great that the existing settling ponds and filters were considered too small for the complete settling and filtration of the necessary quantity of water. General estimates of extensions gave the expense involved, and as it was a question whether, with an increase of capital to the extent of about 150,000 fl., the low tariff here in force would be sufficient to yield the interest on it, the question arose whether such an extension were absolutely necessary, and whether the same object could not be attained in some cheaper way.

"The weekly examinations of the water as to its organic contents had proved that a speed of filtration of 2·1 cubic metres to 1 square metre of surface could not be exceeded without its having a prejudicial influence.

"On most occasions the river water was of such quality that the quantity of organic matter in the filtered water remained below the maximum that had been assumed as a limit not to be exceeded in good drinking water, but sometimes the contrary was observed, and provision was thus distinctly necessary. In foreign periodicals for some time past attention had been drawn to the oxidising effect of iron on the organic ingredients of water. Experiments had shown that when one brought iron into intimate contact with foul water, the water took up a great quantity of iron, which in its turn

was kept back on subsequent sand filtration; at the same time on examination it appeared that the organic matter in the filtered water was very considerably diminished, the ammonia wholly removed, and the noxious microbes annihilated." . . . . . .

The Report proceeds to state how the satisfactory experience gained at Antwerp, and the offer of the inventor's firm to guarantee the success of the iron process at Dordrecht, induced his municipality to conclude a contract with Messrs. R. S. Stokvis and Sons, of Rotterdam, acting on behalf of Messrs. Easton and Anderson, the manufacturers of the revolving purifier:—

"According to this contract the township undertook the construction at its own expense of a proper foundation for the apparatus and of a building for its protection. Messrs. R. S. Stokvis and Sons undertook the delivery and erection of the revolving purifier, with all accessories, guaranteed its good working for six months from the date of completion, and were to receive within fourteen days after the expiration of the term of maintenance a sum of 16,700 fl. and interest at 5 per cent. per annum on that amount for any delay in acceptance beyond three months after completion.

"It was further stipulated that by 'good working' should be understood:

"*a.* The removal of the yellow colour which the river water at Dordrecht exhibits at certain times.

"*b.* The increase in the speed of filtration through the existing sand filters to 4000 litres of water per square metre of sand surface in twenty-four hours.

"*c.* A chemical improvement in the quality of the river water proportionally as great as that in the sample tested by Mr. G. H. Ogston, chemist, at London, of which the official analysis dated 24th November, 1885, was appended to the contract."

The Report next describes the apparatus erected, of which an illustration is given in Plate III., and continues:—

"As it was inconvenient to apply the existing steam-engine for the purpose of turning the purifier, and as a

special steam-engine or gas-motor would have caused too heavy a charge on the working, the pressure of the water leaving the purifier has been utilised for driving a turbine, which in its turn actuates the whole apparatus. In this way the motive power for the purifier costs nothing. . . . . On leaving the purifier the water is much charged with iron, and this iron must be again thrown down by the influence of the air. The better the supply of air is, the better is the object attained. For this reason the water which leaves the purifier flows through a broad open iron gutter of considerable length, from which it is precipitated on to the filters. In this gutter there are barriers fixed, behind which the suspended particles of iron are retained, and which help at the same time to expose continually new portions of the water to the air through the eddying motion they set up in the water. Also, with a view of getting as intimate contact as possible between the water particles and the air, the water then flows over broad steps covered with coke on to the filter bed.

"In ordinary conditions of the river water this arrangement is sufficiently effective, but with the so-called 'thick' river water it appeared that in this way the water could not be got quite colourless. This was ascribed to an insufficient oxidation of the iron, and it was resolved to apply still more air to the water by artificial means. For that purpose a Blower (a sort of air-forcing apparatus) was fixed and driven by the revolving purifier. This apparatus forces air into a zinc box, placed in the open gutter, where it leaves the purifier house; the cover of this box is provided with a number of small holes, by which the air finds its way out and then bubbles with great force and velocity through the water flowing over it. By this arrangement even unusually thick river water was proved to become quite colourless after filtration.

"Repeated experiments and examinations had shown that the water fulfilled the conditions specified under (*b*) and (*c*), but the colourlessness had for a long time been unsatisfactory. We had, however, the good fortune, soon after the application of the last improvements, in the beginning of June last, to get river water thicker than it ever is in winter; and then was proved the efficiency of the arrangement, as it was at that

time. Notwithstanding that it had little time for previous settlement and that it was filtered for several days and nights without intermission at the guaranteed speed, the water remained clear, a fact of which every water consumer at that time was able to convince himself, and with which many even expressed their satisfaction. Chemical examinations were made repeatedly by Messrs. J. A. J. Van den Ven and P. A. Giltay, of this place. Their reports were regularly sent to the burgomaster and aldermen, and though it was evident to each expert that the figures obtained showed fully the improvement guaranteed in the contract, I still thought it desirable, when at length, in my own judgment, the purifier fulfilled all the requirements of the contract, to propose to these gentlemen a final examination, and to ask for their opinion on the working of the purifier in connection with the guarantee given in the contract.

"To this end I submitted to both the gentlemen on 10th June last a sample of the very thick river water, and at the same time one of the water filtered at the guaranteed rate of speed. Their reports, of which copies were sent to the burgomaster and aldermen, were both, without reservation, favourable. They have not hesitated to declare that the method of purification fulfils the conditions specified in the contract. Repeated microscopic examinations by both gentlemen showed that the water obtained, when regarded also from a microscopic point of view, was remarkably improved. . . . . . . I think I must not end this Report without a word of compliment to the contractors and their engineers for the loyal way in which they have fulfilled the stipulations of the contract, whereby my task as engineer has been made much easier. Thanks to their energy, the High-Pressure Water Supply can now look forward with confidence to an increase in the water consumption, and will be in a position continually to deliver a sufficient quantity of good and pure water without the undertaking being too much burdened by the interest on the capital required for it."

The form of the metal used in the Dordrecht purifier, is that of "burrs" from punching machines, varying from $\frac{3}{8}''$ to $\frac{3}{4}''$ in diameter. This form was originally adopted,

because iron borings were found to pulverise too quickly and get into the working parts of the reaction wheel. It appears, however, from the experience gained at Dordrecht since the apparatus was started, that the sand filters choke far less rapidly when the harder form of iron is used. Writing on March 24th, 1888, after certifying to the continued success of the purifier during the winter, Mr. François observes:—

"As to the cleaning of the filters, I may tell you that during the first period of the trials, when we were using the fine iron, the filters had to be cleaned three times against once formerly, but since using the punchings and the coke, they do not get dirty much more rapidly than without the purifier; the coke retains much of the precipitated iron. It was at the end of November that the filters were last cleaned, and since then up to the present time they have filtered about 21,000 cubic metres of water."

Mr. François has also supplied the following information with regard to the bacteriological tests made by Dr. Dupont, of Rotterdam:—

By decantation and ordinary sand filtration the number of microphytes present in the original river water is reduced from 84·6 per cent. to 91·2 per cent.

When the decanted water is passed through the revolving purifier, aërated by the blower, and subsequently filtered, the reduction is from 94·4 per cent. to 95·8 per cent.

Dr. Dupont also found that the reduction in the number of germs effected by the passage of the water through the "revolver," and by mechanical aëration, but without filtration, varied from 7·5 per cent. to 53 per cent. This variation is probably due to the state of oxidation of the iron salts at the moment of taking the samples. It appears probable that the destructive action of the iron process on microbes is most powerful during the formation of the ferric oxide, in the flakes of which the germs are enveloped, if not actually burned up and destroyed, as some authorities consider to be the case. It must be noted that at

Dordrecht the filters are always run at the full guaranteed rate of delivery of 4 cubic metres per square metre per 24 hours—about 90 gallons per square foot—both purifier and filters being stopped as soon as the requisite day's supply has been pumped into the storage reservoir. Also that the samples taken for examination by Dr. Dupont were drawn from a tap on the supply main, the water tested having been momentarily in contact with the air on leaving the filter, and again in the storage reservoir. It may, therefore, be assumed as probable that practically all the germs present in the original water are eliminated by the time the purified water has reached the bottom of the sand. It is well known by experience with the filter beds of the London Water Companies and at Berlin, that the alternate stopping and re-starting of a filter and a high rate of filtration are the greatest obstacles to successfully arresting microbes. The large and regular reduction in the number of germs obtained at Dordrecht under these unfavourable conditions points to the existence of an action which is altogether independent of the mechanical process of ordinary sand filtration. Either the microbes must be coagulated together and imprisoned in the iron precipitate, or this precipitate must be of such a homogeneous and consistent nature that the thin film of it formed on the surface of the sand is capable of arresting the microbes under conditions where an ordinary bed of sand three feet in thickness will let them pass.

The table on page 43, already referred to, gives the results of analysis of the Dordrecht water, as well as of water from Gouda and Antwerp, made in April 1887 by the distinguished chemist and analyst, Dr. Meymott Tidy. It will be noticed that the original sample from the river Merwede was extraordinarily free from ammonia, of which no further reduction was effected by the purification. The oxidisable organic matter was reduced 55 per cent. In the Antwerp samples the ammonia is reduced by 75 per cent., while the oxidisable organic matter shows much

less reduction than usual. The analysis of the Gouda water gives an improvement of 80 per cent. as regards ammonia, and of 60 per cent. for the organic matter.

V.—THE OSTEND TRIALS.

The Town of Ostend, in Belgium, had for many years severely felt the want of a sufficient supply of potable water. The "Canal de Bruges" was the only source affording with any degree of certainty the quantity of water required, but the utilisation of it was impossible owing to its periodical pollution by extraneous waters. The canal is fed by the River Escaut, which is liable to contamination from the waters of the Espierre, a stream flowing through the great wool-washing districts of Roubaix and Tourcoing, on the French frontier. In the spring of 1886 the Communal Council of Ostend voted a sum of 400*l.* to meet the expenses of a thorough trial of the iron purification process as applied to the canal water. A 3-inch Anderson's Purifier, lent by the makers, was erected near the village of Jabbeke, on the banks of the canal, some nine miles above Ostend, and a small sand filter, 150 square feet in area, was constructed alongside it. In addition to the polluted waters of the Espierre, those of the Lys—which, owing to the flax-retting carried on in it, is probably the foulest stream in Belgium—were being diverted into the canal to permit of the construction of a new siphon through which they will eventually flow. The trials were commenced in August and continued until winter set in, being carried out under the very unfavourable conditions mentioned.

In February 1887 the City Engineer, M. E. de Cuyper, published a Report embodying those of Professor Swarts, of Ghent University, and Professor Kemna, of Antwerp, acting respectively for the authorities and for Messrs. Easton and Anderson.

After giving a table of analysis of samples taken at

various periods during the experiments, Professor Swarts says:—

"I think I may dispense with discussing here the process of purification of Messrs. Easton and Anderson. I have studied this process, in collaboration with several chemists of Antwerp, in a work addressed in 1885 to the Communal Administration of Antwerp, and of which I have the honour to send you a copy.

"When one compares the result of the analyses of the water of the Bruges Canal with those which the same water gives after filtration, one acquires the conviction that purification by iron improves this water in a remarkable fashion. Before filtration it is thick, yellowish, almost opaque, when examined through a depth of 60 centimetres; all kinds of lower organisms are seen swimming in it, and when kept for several weeks in a well closed and brightly lighted bottle, confervæ, small crustacea, &c., are seen to develop in it as in a miniature aquarium. I did not think fit to taste it. After filtration over iron the water becomes absolutely limpid and brilliant; when examined through a depth of 60 centimetres it is of perfect transparency, and has a faint greenish tint. Its taste is fresh and agreeable, and, after keeping under the conditions described above, there shows itself at the most a slight greenish deposit, due probably to microscopic algæ, but which may also be seen to develope in bottles of distilled water in the laboratory."

Professor Kemna's Report, which follows that of Professor Swarts, fully endorses the conclusions of the latter, and M. de Cuyper adds:—

"To the two reports and note which you have just read, I think I have nothing to add in order to convince you of the efficacy of the process, as to which I expressed my conviction in my previous reports. There is, however, one point to which I must call all your attention; it is the state of the canal during the period of the trials. Since the middle of July the waters of the Bruges Canal have been contaminated by the waters of the Escaut. This contamination, due to two causes, the retting of flax in the waters of the Lys and the discharge of the polluted waters of the

Espierre, lasted until the middle of November, and it was only at that time that the canal returned to its normal state. I will not hide from you that, in the presence of these facts, I hesitated a moment in continuing to propose to you the Bruges Canal as a source of supply. In fact, in spite of the assurance I had of the efficiency of the Easton and Anderson process, I did not conceal from myself the difficulty which there would be in making the population understand that it was possible to render this black and stinking water, in which all the fish were dying, potable and fit for every use."

In order to further satisfy the authorities and the public, the trials were recommenced at M. de Cuyper's request in the spring of the following year. The canal water was worse than before, but so successful was the second experiment, that instead of lasting two months, as at first intended, the purifier was kept at work during the whole of the very dry summer of 1887, so that the purified water might be sent daily into Ostend and supplied for drinking purposes to any who chose to fetch it. Being now perfectly satisfied, the authorities have decided to adopt the Anderson process on the large scale, and plans for the establishment of permanent works at Jabbeke are under consideration.

VI.—THE PARIS TRIALS.

During the summer of 1886, a $1\frac{1}{2}$-inch purifier was erected in Paris at the ironworks of the Société des Anciens Établissements Cail.

These works are situated on the Quai de Grenelle, below the city. The Seine water utilised at the works was unfit for drinking purposes, being generally turbid and of course liable to be polluted at this point of the river. Experiments carried out before the engineers of the city, showed that five minutes' contact with iron borings followed by a rapid sand filtration rendered this water perfectly limpid in appearance and chemically pure and suitable for potable purposes. The interest of the experiment was enhanced by the fact that the city authorities were at

that time promoting a bill in the House of Deputies to expropriate certain "springs" fed by the river Avre, in the Department of Eure et Loir, and to bring this so-called spring water to Paris at a cost estimated by the promoters at 2¼ millions sterling. Strong opposition was offered to this scheme by the millowners and river-side proprietors on the Avre, and by the deputies representing the districts likely to be affected by the loss of the Avre water. The possibility of rendering the waters of the Seine as good, or better than the proposed spring water supply, was therefore a question of the greatest moment to the opponents of the City scheme, and the trials made at the Cail Company's Ironworks were watched by them, as well as by the City Engineers, with much interest. M. Marié-Davy, the eminent head of the Montsouris Observatory, and Consulting Chemist to the City of Paris, was requested to investigate the process and to give his opinion upon it as applied to the Seine water taken at the point mentioned. This he did in a Report dated 12th December, 1886. As pointed out by M. Marié-Davy, the river water was at this period comparatively pure, containing, when tested by the French method, neither free nor albumenoid ammonia (that is to say, probably less than 0·30 parts per million, by Wanklyn's test). M. Marié-Davy first turned his attention to the improvement effected by the iron process in the colour of the water. The Seine water may generally be rendered fairly colourless by simple filtration, and the chemist was at first sceptical as to the power of metallic iron to remove more colour than filtration through sand would do. Taking the wonderfully limpid and blue water of the Vanne as a standard, and measuring the thickness of the layer of yellow which had to be placed in front of a tube, two metres long, containing Vanne water, in order to correspond with each sample under comparison, it was found that Seine water filtered through Pasteur's biscuit porcelain filter was as 2; distilled water as 3; Seine water purified by iron and subsequently filtered through sand as 5; and Seine water filtered through filter paper

as 10 to the zero of the standard. Under the head of "Mineral Analyses," the Report states that the temporary and permanent degrees of hardness of the Seine water are reduced respectively 10·6 per cent. by iron purification. In the third portion of his Report, dealing with "Organic Analyses," M. Marié-Davy states that the natural Seine water under examination contained neither free nor albumenoid ammonia in sensible quantities, and that he was therefore unable to appreciate the effect of the iron process on them. He, however, found the oxidisable organic matters reduced 40 per cent. by the purification. He adds:—

"The quantity of organic matter contained in the water still seeming to us too small, we operated on two occasions on some water drawn from the main-sewer at Clichy, and filtered afterwards through paper. We have arrived at the following results:—

I.	Sewer water, unpurified	25·1
	" " purified by cast-iron borings	2·9
	Reduction, 88 per cent.	
II.	Sewer water, unpurified	45·0
	" " purified by cast-iron borings	6·1
	Reduction 86 per cent.	

"We think that this proportion must change with the nature of the organic matter and its quantity."

The last portion of the Report is devoted to "Biological Analyses." Various samples drawn respectively from the Seine, from the outlet of the purifier, and from different points after filtration were submitted to the gelatine test with the view of establishing a comparison of the rapidity with which liquefaction of the nutritive medium commenced and was completed. In the case of the river water, simply filtered through sand, liquefaction began after 1·6 day, and was complete in 10·9 days, while with purified water, drawn immediately under the sand filter, liquefaction commenced after 3·1 days, and was complete in 12·13 days. M. Marié-Davy concludes his Report by saying that the results obtained from his biological analyses are insufficient, and states his intention of making

a lengthened study of the power of the Anderson process to destroy bacterial life.

It has been mentioned that by his method of analysis, the French chemist was unable to establish to what extent the iron process reduced the free and albumenoid ammonia in the case of the Seine water, his tests showing none, either before or after purification. The delicate process of Wanklyn, so generally relied on in England to determine the degree of pollution of a water, as shown especially by the amount of albumenoid ammonia it contains, is little used on the Continent, foreign analysts attaching more importance to the determination of the oxidisable organic matter by the permanganate of potash test. Without entering into a discussion as to the relative merits of the English and foreign practice, it may be stated that Wanklyn's method of analysis when applied to the Seine water showed that, in this case also, the usual striking reduction of the free and albumenoid ammonia took place after treatment with iron. Analyses made by Professor Kemna, in Antwerp, in October 1886, of samples from the Cail Company's Works gave the following results:—

Seine Water.	Organic matter.	Free Amm.	Alb. Amm.
Filtered through sand only ..	0·058 grs.	0·40 mill.	0·16 mill.
Purified by iron	0·025 „	trace.	0·06 „

In view of the interest taken in the Paris experiments by the opponents of the Avre "spring" water scheme, a comparative analysis was also made by the same chemist of four samples of this proposed source of supply, drawn from what are known as the "springs of Rueil."

	Organic matter. grs.	Free Amm. mill.	Alb. Amm. mille.
Springs of Rueil, No. 1 ..	0·022	0·04	0·08
„ „ „ 2 ..	0·021	0·01	0·11
„ „ „ 3 ..	0·021	0·02	0·10
„ „ „ 4 ..	0·021	0·02	0·07
Mean	0·021	0·02	0·09

From these figures it will be seen that, taking the ammonia present in each sample as the criterion, Seine

water taken below the city of Paris is, after iron purification, at least 30 per cent. purer than that from the Rueil springs, and contains only 0·003 grammes per litre more oxidisable organic matter. There can be no doubt that, if drawn from a point above the city, the Seine is capable, when purified by iron, of affording a supply at least as pure as the costly spring water scheme would furnish, and one certainly more inexhaustible.

VII.—THE LEA BRIDGE TRIALS.

Though not strictly falling within the scope of this work—which was intended as a record of the results obtained from the various applications of Mr. Anderson's process coming within the personal experience of the writer—it will not be out of place to refer here to the very important experiments carried out in 1885, at the Lea Bridge Works of the East London Waterworks Company, under the direct supervision of the inventor of the revolving An apparatus delivering 500 gallons per minute erected and kept at work for a lengthened period in connection with one of the permanent sand filters of the Lea Bridge Pumping Station. In their Report to Mr. W. B. Bryan, Engineer to the Company, dated October 28th, 1885, after enumerating certain difficulties which had to be overcome before the sand filter could be brought to work exclusively with the purifier, Messrs. Easton and Anderson say:—

"The proper quantity of iron in relation to the size of the apparatus, the speed at which it is driven, and the quantity of water passing through it per minute, having been ascertained, samples have been taken for examination and analysis, and the results appear to be extremely satisfactory. As to colour, as seen in the usual two feet tube, there is a great improvement as compared with samples taken on the same day from the Company's filtered water reservoirs, nothing but a faint apple-green tint remaining; whilst, what is of more consequence, the amount of organic matter, represented

especially by the so-called albumenoid ammonia, is greatly reduced, and is brought down, in fact, to a point beyond which the purest waters never pass."

The Report concludes with the following table of analyses, in which the progressive improvement of the sand filter, to which attention has been already drawn (p. 25), is well exemplified:—

		Free.	Ammonia Albumenoid.
Samples taken 1st Oct., 1885	Company's ordinary water ..	·040	·040
	Purified water	·015	·020
Samples taken 9th Oct., 1885	Company's ordinary water ..	·010	·030
	Purified water	none	·010
Samples taken 13th Oct., 1885	Company's ordinary water ..	·010	·030
	Purified water	none	·010

"The samples taken on the **1st** October were not very good, but those taken after that date, when the apparatus was in full work, show a degree of purity which leaves nothing to be desired."

It should be added that for these trials a 12-inch apparatus was used, capable of purifying 954,100 gallons per 24 hours. The experiment was therefore made under the exact conditions of working on the large scale.

VIII.—THE BERLIN TRIALS.

This record of the numerous experimental and permanent applications of the iron process of purification must be completed by a reference to the trials which took place at the Stralau Station of the **Berlin Municipal Waterworks,** in 1886. In spite of the unusually large amount of care and scientific experience brought to bear in the working of the sand filters through which the Spree water is passed before distribution, the results obtained leave room for improvement both as regards the appearance of the filtered water and its chemical quality. It was hoped that this was a case where agitation with iron would be as successful as it had proved elsewhere, both in removing colour, and reducing organic matter, and at the request of Mr. H. Gill, M. Inst. Civil Engineers, the well-known head of the

Berlin Municipal Waterworks, a 3-inch revolver and motor were lent by the inventors for a prolonged trial. A special sand filter was constructed in connection with this apparatus, and trials were carried out under the supervision of Mr. Piefke, Assistant Engineer of the works. This gentleman has made known the results of his experiments with the revolving purifier in a pamphlet published in 1887.* As has been already mentioned, the Berlin trials did not give such uniformly successful results as has been hoped for, and as would have been necessary to justify the adoption of Mr. Anderson's process on the large scale, without some modification. At the same time the statistics given by Mr. Piefke, show that excellent results were obtained during several lengthened periods of the trials and under certain conditions of working. The difficulty encountered in treating the Spree water with iron was that of a reaction which appeared to take place after purification, some of the iron being redissolved, and after passing through the sand filter in a soluble state, precipitating as ferric oxide in the filtered water. Various theories have been proposed of the cause of this reaction, which, it is interesting to note, gave precisely similar results during the official trials of Professor Bischof's "spongy iron" filter, previously made in Berlin with the same water. In the case of the spongy iron filter, the reaction was ascribed to the presence of salts of iron in unusual quantities in the original water, and the writer inclines to the belief that this explanation is the true one to apply to the revolving purifier trials. It was noticed that at the moment of leaving the sand, the filtered water was invariably quite colourless and brilliant; after a short exposure to the air, the sample began to acquire a yellowish tinge, and eventually became red; a deposit of ferric oxide being finally formed. A parallel to this chemical reaction was obtained in the laboratory at Antwerp by passing a second time through the purifier a sample of

* Die Principien der Reinwasser—Gewinnung vermittelst Filtration. Von C. Piefke. Abstracted 'Proceedings Inst. C.E.,' vol. xcii. p. 467.

Antwerp water in which the ferrous salts had had time for oxidation after the first purification, but from which the precipitate had not been removed by filtration. The filtration of this twice purified sample produced a water which was at first of unusual brilliance, but which slowly became coloured, and after several hours' exposure to the air gave a red precipitate. In this case, as probably with the Spree water, two salts of iron, in different stages of stability, were brought into contact and reacted upon each other, the one robbing the other of its oxygen, with the result that, in the absence of an excessive supply of oxygen from an extraneous source, an unstable protosalt of iron passed in solution through the filter. It is not intended to discuss here the chemical aspect of this question, interesting though it is, but it may be mentioned, for the benefit of future experimentalists, that the mixture of a small proportion of metallic zinc with the iron granules in the laboratory "revolver," entirely prevented the reaction from taking place, and made it possible to obtain a permanently colourless sample with the Spree water after a rapid sand filtration. The filtered water had, however, a strong metallic taste.

At the commencement of the trials at Stralau, on June 22nd, 1886, and for several weeks afterwards, a duration of contact with the iron of 6·6 minutes was maintained, the sand filter being regulated to a rate of $2\frac{1}{2}$ cubic metres per square metre per 24 hours. Under these conditions, no good results were obtained, the filtered water always becoming coloured. On August 4th the duration of contact was increased to twenty minutes, and the speed of filtration reduced proportionately to the slow rate of 0·8 cubic metres; under these conditions results were far better. The following table given by Mr. Piefke shows that during a continuous trial lasting 41 days, the Spree water treated by iron was on 6 days inferior in appearance to the water supplied to the city, equal to it on 6 days, and superior to it on 29 days. It will be noticed that with the exception of a few days after the experimental sand filter was cleaned,

there was a progressive improvement, probably due to the causes mentioned in Chapter V., and generally observed as taking place with this process. It is much to be regretted that no record is given in connection with this table of the chemical improvement effected in the water, particularly with respect to the ammonia. It would have been interesting to know whether as the filter improved in its action the ammonia progressively diminished in quantity.

Although giving no information as to the chemical improvement effected by the iron, the table furnishes very interesting and valuable statistics, when taken in comparison with other information supplied by Mr. Piefke in the first part of his work, as to the important rôle which the formation of the iron precipitate plays in arresting micro-organisms. A daily examination of the water issuing from one of the ordinary sand filters at the Stralau Works showed the number of germs per cubic centimetre of the filtered and unfiltered water to be as follows (p. 11):—

	Filtered water.	Spree water.
Oct. 6	1488	—
„ 7	864	8,000
„ 8	336	5,040
„ 9	330	21,600
„ 10	260	24,480
„ 11	630	31,185
„ 12	310	26,752
„ 13	528	26,432
„ 14	248	14,600
„ 15	140	4,307
„ 17	88	—
„ 18	99	—
„ 19	73	2,592
„ 21	46	5,328

Referring to this table, Mr. Piefke remarks:

"The result of filtration thus remained rather defective for about 14 days, and then only began to be regular and better."

Another experiment (p. 14) made in April under apparently more favourable conditions, showed that it was not until the sixth day's working that the number of germs

Date.	Volume of Water filtered daily. cub. m.	Average quantity per hour. cub. m.	Germs developed in 1 c. c. Unfiltered Water.	Germs developed in 1 c. c. Filtered Water.	Observations.
Aug. 4	21	1·8	..	..	Filtered water of yellow colour.
5	46	1·9	9,177	678	Filtered water inferior to main water in colourlessness and transparency.
6	48	2·0	..	..	Filtered and main water equally good as to colour.
7	48	2·0	15,839	89	idem.
8	48	2·0	..	..	idem.
9	53	2·2	14,720	96	Filtered water a little darker than main.
10	56	2·3	..	..	Filtered water a little brighter than main, both equally transparent.
11	56	2·3	4,516	60	Filtered water less coloured than main, but not quite colourless.
12	57	2·4	..	..	idem.
13	56	2·3	7,564	57	idem.
14	56	2·3	..	..	Filtered water brighter than main, but not so transparent.
15	53	2·2	..	..	Filtered water better than main, though not absolutely colourless.
16	49	2·0	6,343	42	idem.
17	47	2·0	..	..	
18	47	2·0	3,381	65	
19	48	2·0	..	..	
20	48	2·0	..	..	
21	48	2·0	..	..	
22	41	1·7	..	..	
23	40	1·7	13,906	87	
24	12	2·0	..	..	
Total Water Filtered, 978m 3. Filter cleaned.					
28	57	2·3	8,776	2115	Filtered water not yet clear and of yellow colour.
29	58	2·4	..	..	idem.
30	57	3·3	14,769	121	Filtered water not transparent, but same in colour as main.
31	58	2·4	..	..	Filtered water transparent and more colourless than main, but not perfectly colourless.
Sept. 1	58	2·4	..	..	
2	60	2·5	..	..	Filtered water very transparent and all but colourless.
3	56	2·3	7,936	93	idem.
4	57	2·4	..	..	
5	58	2·4	..	..	
6	57	2·4	3,140	95	
7	58	2·4	..	..	
8	56	2·3	11,227	109	
9	59	2·5	..	..	
10	56	2·3	..	120	
11	53	2·2	..	..	
12	56	2·3	..	..	
13	49	2·0	..	..	
14	56	2·3	..	..	
15	38	1·6	..	..	
16	7	1·1	..	..	
Total Water Filtered, 1064m 3. Filter cleaned.					

was reduced below 100 per cubic centimetre. A comparison of the statistics given for the experimental filter with those of the ordinary sand filters, shows that with the iron process the filter obtained its full degree of efficiency in retaining the micro-organisms in from two to three days. It has been stated by Mr. Gill (Inst. Civil Engineers, vol. lxxxv.), and confirmed by Mr. Piefke, that the choking up of the pores of the filter by the arrested impurities, and, during the summer months, the growth of algæ at the surface of the sand, are the most valuable aids, in the case of ordinary sand filtration, to the micro-biological improvement of the water. It would appear then that, from the micro-biologist's point of view, a foul filter is a necessity if not a desideratum. With the iron process, however, it seems possible by means of the coating given to the sand by the precipitation of the iron oxides, to obtain the desired reduction of the organic germs while maintaining for an indefinite time, as has been proved at Antwerp, a pure filter. Surely, admitting the importance of arresting the passage of 98 or 99 per cent. of the microbes, it is worth considering whether the escape of the remaining one or two per cent. in water capable of furnishing as much ammonia for their nutriment and development as a foul filter must supply, is not likely to be as dangerous to the public health as the presence of a greater number of germs in a liquid unfavourable to their growth and increase. Of Mr. Piefke's Report it must be said that he endeavours to reconcile every result he noticed with a preconceived theory of his own, that purification by iron is due exclusively to a physical "surface action," the organic matter being oxidised directly by the oxygen occluded on the surfaces of the iron granules, and that a precisely similar beneficial action may be relied upon, though to a less powerful extent, when passing impure water through a well aërated sand filter. In this he entirely ignores the whole chemical history of purification by iron, and the overwhelming mass of proof in the numerous cases with which he is not personally acquainted, of the important

part which carbonic acid plays in the process. One experiment repeatedly made in the Antwerp laboratory may be mentioned in support of the claim that the formation of ferrous carbonate is the first stage of the purification. At Antwerp the river water loses 50 per cent. of its organic matter by its purification by iron, followed by aëration and filtration. Filtered water, however, drawn from the city mains and again passed through a purifier, gives no further improvement, unless carbonic acid is first added to it, when a considerable reduction of the organic matter again takes place. Mr. Piefke, in support of his theory of surface action, describes an experiment he made and which succeeded when the ordinary method of iron purification failed. Forming a filter 70 centimetres thick of coarse granules of iron, he caused a strong current of air to pass upwards through the iron layer while the water flowed downwards, and obtained thus, after a rapid sand filtration, a very brilliant sample and a reduction by sixty per cent. of the oxidisable matters contained in the original water. It is probable that it was this artificial introduction of an excess of oxygen that was wanted, in the case of the revolving purifier, to prevent the reaction before filtration to which the failure of the trials was due, and it is much to be regretted that the result of the trials was not made known until the experimental plant was dismantled, as it would have been interesting to test this with Mr. Anderson's apparatus. The good results obtained with the longer contact and the proportionately slow filtration may be ascribed to the lengthened period allowed for natural aëration of the water. While apparently not admitting the possibility of applying the iron process to the Berlin water, Mr. Piefke says in closing his Report:—

"In conclusion, we must again insist upon the excellent service rendered to clayey waters by treatment with iron previous to filtration. The particles of ferric oxide mixing in the water encase the finely divided matters and rapidly draw them down, so that filtration may be effected after a short period of settlement. The ordinary difficulties were

found to be completely removed from the moment that a coagulating substance, ferric oxide, was formed. The ferric oxide that remained deposited on the surface did not reduce the delivery of the filter to any sensible extent."

IX.—NOTE BY PROFESSOR KEMNA.

At the request of the writer, Mr. Kemna, Doctor of Sciences and Professor of Chemistry and Natural Sciences at Antwerp, whose name has been already frequently quoted in connection with various analysis and experiments, has been good enough to give the following résumé of his experience of the iron purification process:—

"In my capacity as chemist to the Antwerp Waterworks Company, I have for more than two years been studying the application of iron to the purification of water; I have further had to follow regularly all the trials made elsewhere on a large scale—in Belgium, Holland, France and Germany From these researches, bearing upon waters very varied in nature, result the following general rules:—

"(1) A *complete* removal of the free ammonia. Whatever may be the quantity present in the original water, only a negligeable trace of it should remain in the purified water. In July 1887, the water of the Bruges Canal at Ostend gave regularly more than 1·00 milligramme per litre of this form of ammonia; the purified water only showed traces. Below are the figures:—

	14th July, 1887.		26th July.		2nd August.	
Ammonia	Free	Alb.	Free	Alb.	Free	Alb.
Canal water	1·00	0·35	1·05	1·50	2·25	0·50
Purified water	trace	0·21	trace	0·23	0·05	0·27

"(2) A reduction of 75 per cent. of the albumenoid ammonia. With very impure waters, this proportion is generally greater; it is less with fairly pure waters, and it seems that for each kind of water there is a particular minimum, below which it is difficult to arrive.

"(3) A reduction of 40 to 50 per cent. of the total organic matter tested by Kubel and Tiemann's permanganate of potash method. As with the albumenoid ammonia, this reduction is often much more considerable with bad water, sewer water for instance.

"The mechanism of the process, that is to say, that which takes place inside the revolving cylinder, and during the subsequent aëration, is a very arduous problem. It is probable that there are at the same time numerous physical actions, and no less numerous chemical 'phenomena.' I have studied the question, in collaboration with Mr. Devonshire; but I think it right to point out here that every one-sided explanation, every theory which does not take into account all the elements of the question, will inevitably lead to erroneous conclusions. This remark applies especially to a recent work by Mr. Piefke, entitled 'Die Principien der Reinwasser-Gewinnung vermittelst Filtration,' in which the action of the iron is considered as solely a 'surface action,' and in which the whole of the chemical part of the process is passed over in silence.

"The filtration through sand, which completes the operation, has not a preponderating importance in the iron process; the filter only plays a mechanical part in order to retain at its surface a colloidal layer of ferric oxide. Numerous laboratory experiments have shown that a rapid passage through one decimetre (4 inches) of sand was often as efficacious as a slow filtration through a bed 3 feet thick. The fact is that the chemical actions are terminated when the water arrives on the sand, and that the film of oxide, once formed and well settled, constitutes a homogeneous and continuous membrane, through which the water passes, not by a flow through the interstices or capillary 'transpiration,' but by a veritable osmosis. Also the lower layers of the sand remain remarkably active. It is generally admitted, and all writers on this subject insist strongly, that it is necessary to aërate and frequently renew the filtering material. It is evident that wherever a filter has to accomplish throughout its mass chemical actions dependent upon the oxygen condensed at its surfaces, plus a retentive action of adhesion—it is evident that there the purifying action diminishes rapidly. For the last six years that they have been at work, the filters at

Waelhem show no sign of choking up. In the early part of 1887, when some English vistors had manifested their lively apprehensions on this point, the Board of Directors would not have recoiled before the expense of a complete renewal of the sand; I resisted the taking of this step, as one which the analyses of the purified water did not justify.

"Yet another reason led me to oppose any renewal of the sand. This reason is set forth in my report of the 13th of November, 1886, on the Ostend experiments, when I wrote: 'I have said that the iron process removes all the free ammonia. This is so true, that in the water of the Antwerp supply there is less free ammonia than in the water of the Vanne, the best of the Paris supply (see my comparative analysis of the 7th ult.). Now the Ostend water often shows some, and that in a very appreciable manner. I think the cause must be sought for in the manner in which the process is applied, and especially in the want of experience of the 'personnel' called upon to manipulate the filters, a want of experience which is inevitable at starting. Moreover, the filter is new, and it is known that use, far from diminishing the efficacy of a sand filter, on the contrary increases it. In the filters at Waelhem the whole of the sand is coated with a slight film of ferruginous nature, and it is to this substance that I believe the power of retaining ammonia is to be attributed. At Ostend, on the contrary, the filter is too new, but it is progressively improving. If we take the analysis of the 23rd of October, 1886, when for 0·80 milligrammes of ammonia in the river we find 0·33 milligrammes in the purified water, we see that on the 4th of November following, the canal doubled the ammonia it contained, while the purified water, on the contrary, fell from 0·33 milligrammes to 0·18 milligramme per litre, and even to 0·05 a few days later, the canal remaining, however, above 1·00 milligrammes. That which appears to me to corroborate this view is the comparison of the quantity of iron held by the water before and after purification. Generally the Antwerp water contains 0·0005 grammes of metallic iron per litre; I have never found less than 0·0003 grammes. The canal water at Jabbeke gives 0·0004 grammes, and the purified water only 0·00015 grammes. It is probable that the sand arrests and fixes the difference at the surface of its grains."

"In all cases where, from some cause or other, a filter has been disturbed, the quality of the water is immediately affected by it. About two years ago a hole one metre square had been dug in one of the Waelhem filters, in order to investigate the underlying layer of gravel. I had not been informed of the fact, but the apparition of a small quantity of free ammonia at once revealed to me that something abnormal had taken place. In December 1887, one of the filters having been frozen, gave, during the first few days' working, very bad results, and only became comparable to the other filters many days afterwards.

"The point, which is by far the most important, is the action of the iron on microbes. Mr. Ogston's experiments clearly establish the sterility of waters treated by iron, when the numerous causes of error, inherent in this class of research, are avoided. This evidently does not mean to say that ten or twenty thousand cubic metres of water purified in one day will disclose no microbe. The air has access in the reservoirs, in the pumps, and in the thousands of taps placed on the supply pipes. But one may legitimately hope to arrest the organisms brought by the river, and that is the principal thing. In these questions of health, man himself still remains, unfortunately, the best reagent. At my request the Waterworks Company at Antwerp has asked the medical body of that town to proceed to a permanent inquiry as to typhoid fever in connection with the water supply. It is to be regretted that, up to the present, this work, of such utility, has not been able to be undertaken.

"The mechanism of this sterilisation has been attributed by Dr. E. Frankland to the fact that iron has a veritable toxical effect on micro-organisms. This view does not seem to me to be confirmed by the facts. On leaving the 'revolver' the water is as rich in micro-organisms as before. This has been shown by several analyses made by Dr. Van Ermengen, the well-known bacteriologist of the University of Ghent. Nevertheless, it is probable that iron, either in its metallic state or in its state of a compound in solution or precipitated, is a very unfavourable medium for the development of the majority of microbes. But there is another mode of action, to which Mr. Folkard has drawn attention. The insoluble ferric oxide, which forms in the whole mass of the liquid,

produces a veritable coagulation, and, as has been said above, a continuous film of it is deposited on the surface of the sand, through which the water passes, not by capillary transpiration, but by an osmotic or dialytic process.

"The superiority of this iron process is strongly marked when one remembers that, according to Mr. Morris ('Proc. Inst. Civil Engineers,' vol. lxxxv. p. 240) and Mr. Gill, manager of the Berlin Waterworks (ibid., p. 249), one of the most efficacious elements of a sand filter is the coating of algæ, &c., which end by developing themselves on the surface of the sand, and which retain the microphytes. The discordant results of covered and open-air filters, and during different seasons, are in a great measure attributed to the difference of conditions which had allowed a rapid growth in certain cases and retarded it in others. This has evidently not the value of a colloidal film of iron oxide, especially as we can in this case regulate the action at our will, whereas the growth of algæ, under three feet of water, depends upon temperature, light, and the composition of the water, all matters over which we have not the least control.

"It is precisely this possibility of a control, of a direction of the different stages constituting the purification, that renders the iron process more scientific and hence superior to others. My colleagues on the Commission of 1885 said this in reference to the 'revolvers':—

"'The Commission recognises that the Anderson purifiers constitute a great step in advance over the filtering basins. Well handled, they appear of at least equal efficiency; they are much more economical, they are more scientific in character, in that they allow of proportioning the duration of contact to the degree of impurity of the water.'

"The majority of these remarks apply equally to the filters.

"All these considerations appear to me to justify Mr. Gill's remark, that 'the Anderson process is an advance in the right direction.'"

X. — CONCLUSION.

In the somewhat lengthened description and history of the purification of water by iron in the revolving purifiers, the writer has only incidentally touched upon the application of the process to sewage water, preferring to confine himself to recording the practical results obtained in purifying water for potable supply on a large scale. Several experiments and trials have however been made, some of considerable magnitude, which show that success may confidently be hoped for in the treatment of sewage by agitation with metallic iron. The remarkable reduction of organic matter obtained in the laboratory by M. Marié-Davy, when experimenting on water from the Paris sewers, has already been mentioned (p. 54), and similar satisfactory results have been obtained in the Antwerp laboratory. Mr. Anderson has successfully dealt with sewage effluent from Hertford, converting it into a drinkable water, and some experiments at the Crossness Outfall of the Metropolitan sewers, have also given encouraging results. It is interesting to note that in the method for purifying sewage by electricity recently patented by Mr. Webster, iron plates are to be used for transmitting the current. The ultimate aim in purification by iron, now rendered practicable by Mr. Anderson's invention, is the rapid production in their nascent state of oxides of iron. It is probable that the iron plates in Mr. Webster's method will furnish the purifying medium, the electrical current adding powerful extraneous aid in the formation of the oxide. It is worthy of investigation how far the purification would go in Mr. Webster's process, were the chemical solution of the iron plates prevented by coating them with graphite, and reliance placed upon the electrolytic action alone.

Many other experiments have been made in the Antwerp laboratory, and elsewhere, mainly with the view of increasing the rapidity of the formation of the ferric oxide. One plan which promises success has been tried

by the writer. It is found that although, as already mentioned (p. 18), the casual and unregulated introduction of air into the purifier is to be avoided, good results follow the passing of compressed air through the water during its contact with the iron in the revolving cylinder. On this point, as in many more in the iron process, much remains to be tried and elucidated. The subject is still in its infancy, and no more is intended in this work than to record, for the benefit of his fellow investigators, what the writer knows of the present stages of its growth.

For the benefit of any who may be interested in the subject, any further information as to its progress and results will be gladly furnished at all times by the author; Messrs. Easton and Anderson, Limited, 3, Whitehall Place, London, S.W.; Messrs. Cail & Co., 15, Quai de Grenelle, Paris; and Messrs. Stokvis and Son, Rotterdam.

In conclusion, the writer desires to express his thanks to Mr. Anderson, Professor Kemna, Mr. François, Mr. Becking, and others who have supplied him with valuable information and statistics.

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A ...... *Revolving Cylinder*
B¹ B² ... *Hollow Trunnions*
C¹ C² ... *Pedestal Bearings*
D. D. ... *Caved Shelves*
E ...... *Inlet Pipe*
F ...... *Outlet Pipe*
G ...... *Distributing Plate*
H. H. ... *Regulating Blades*
I ...... *Annuler Spur Wheel*
K ...... *Inverted Bell-mouth*
L ...... *Sluice Cock*
M ...... *Air Cock*

ANDERSON'S PATENT REVOLVING PURIFIER.

THOS BELL & SON, LITH 40, KING ST COVEN

A.A.A. *Revolving Purifiers*
B.B. *Wall Steam Engine*
C.C.C. *Inlet pipes and Valves*
D. *Outlet Tank*
E. *Roots' Air Blower*
F.F. *Air Supply Pipes*
G.G. *Perforated False Bottom in Aërating trough*

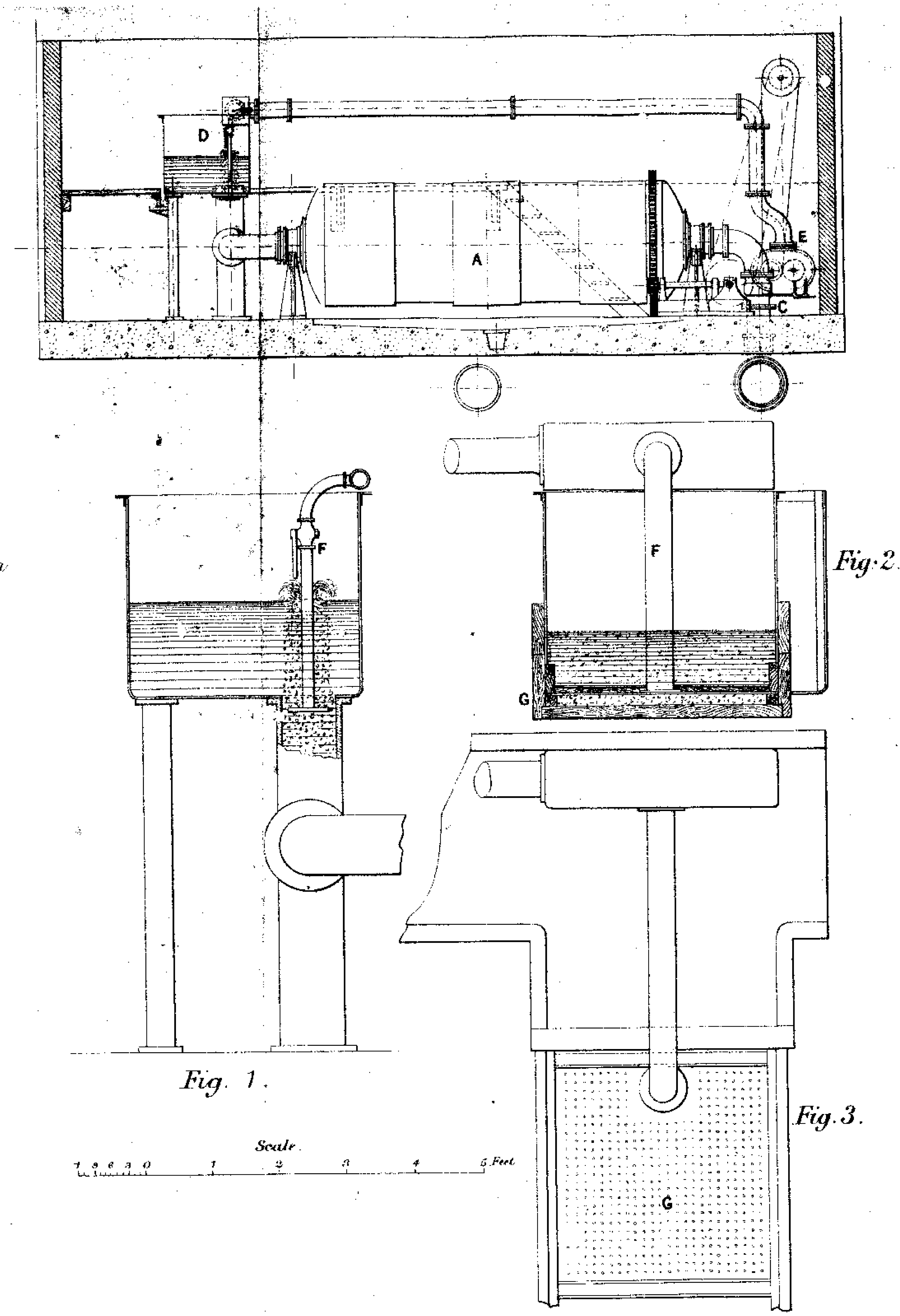
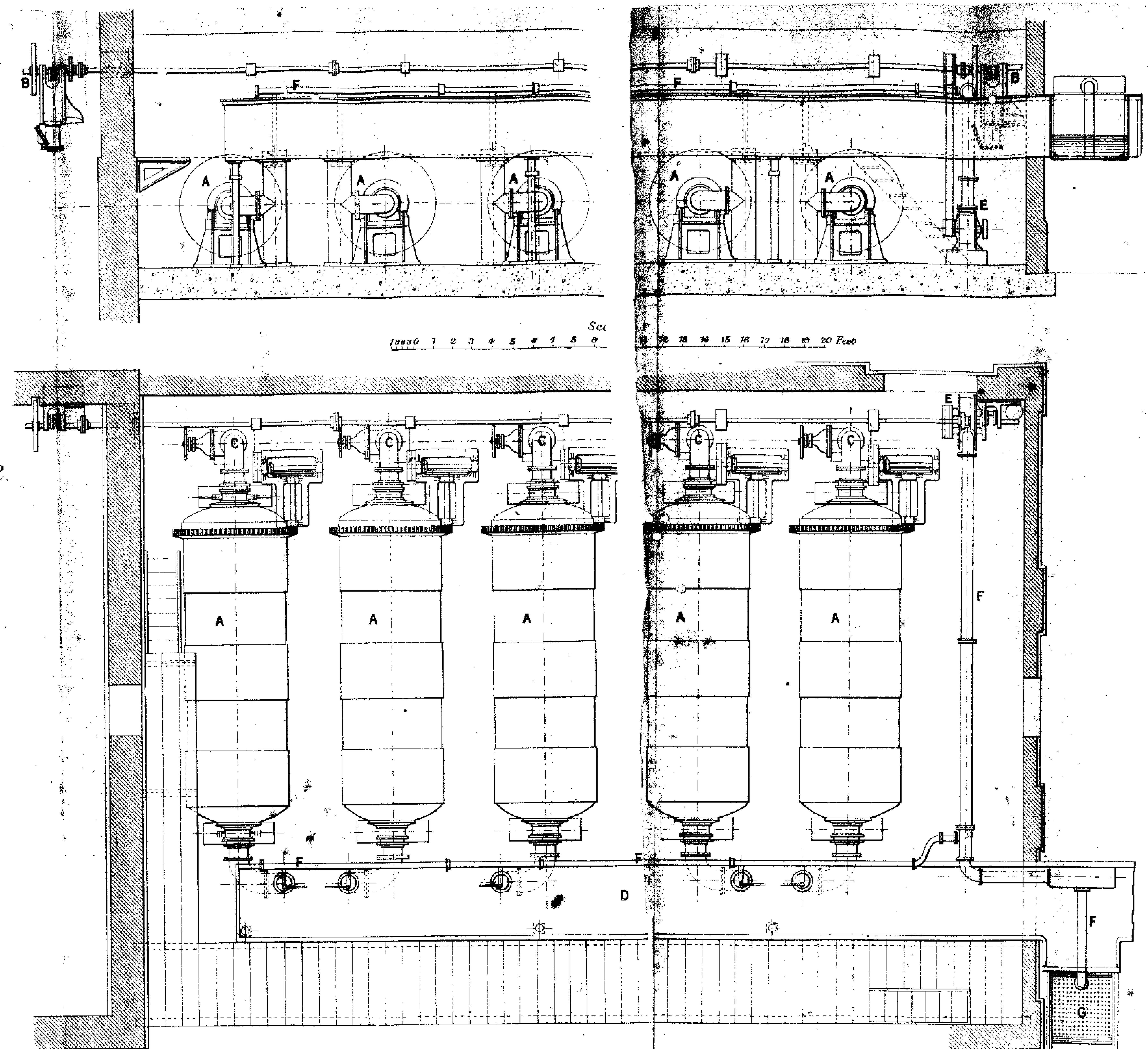


Fig. 1. *Fig. 2.* *Fig. 3.*

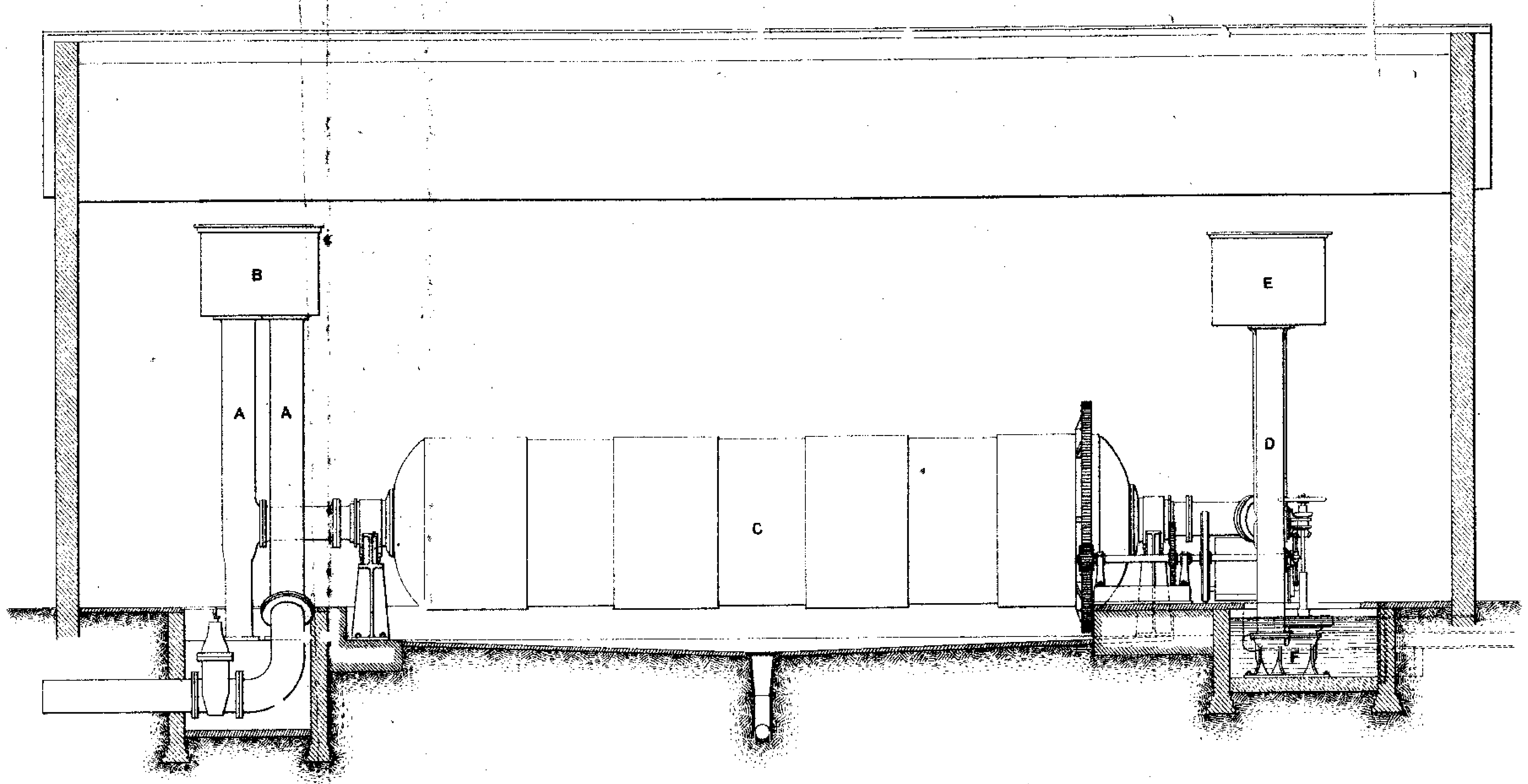


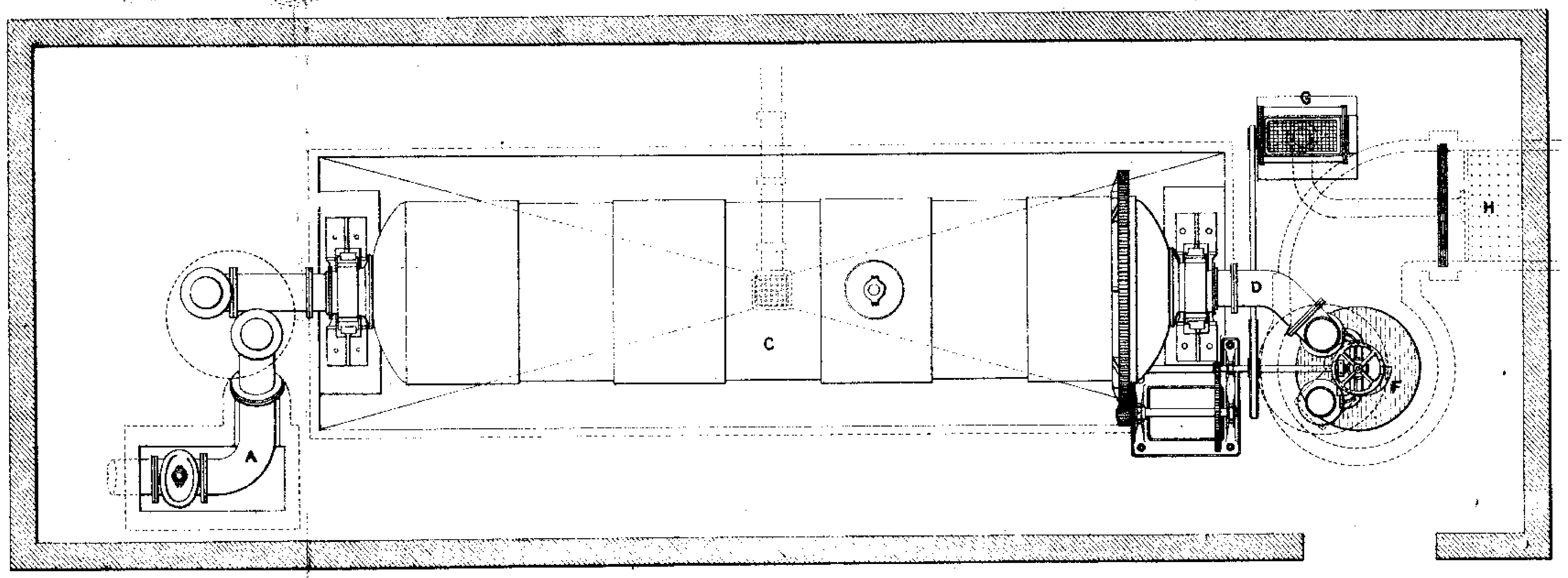
ANTWERP WATER WORKS.

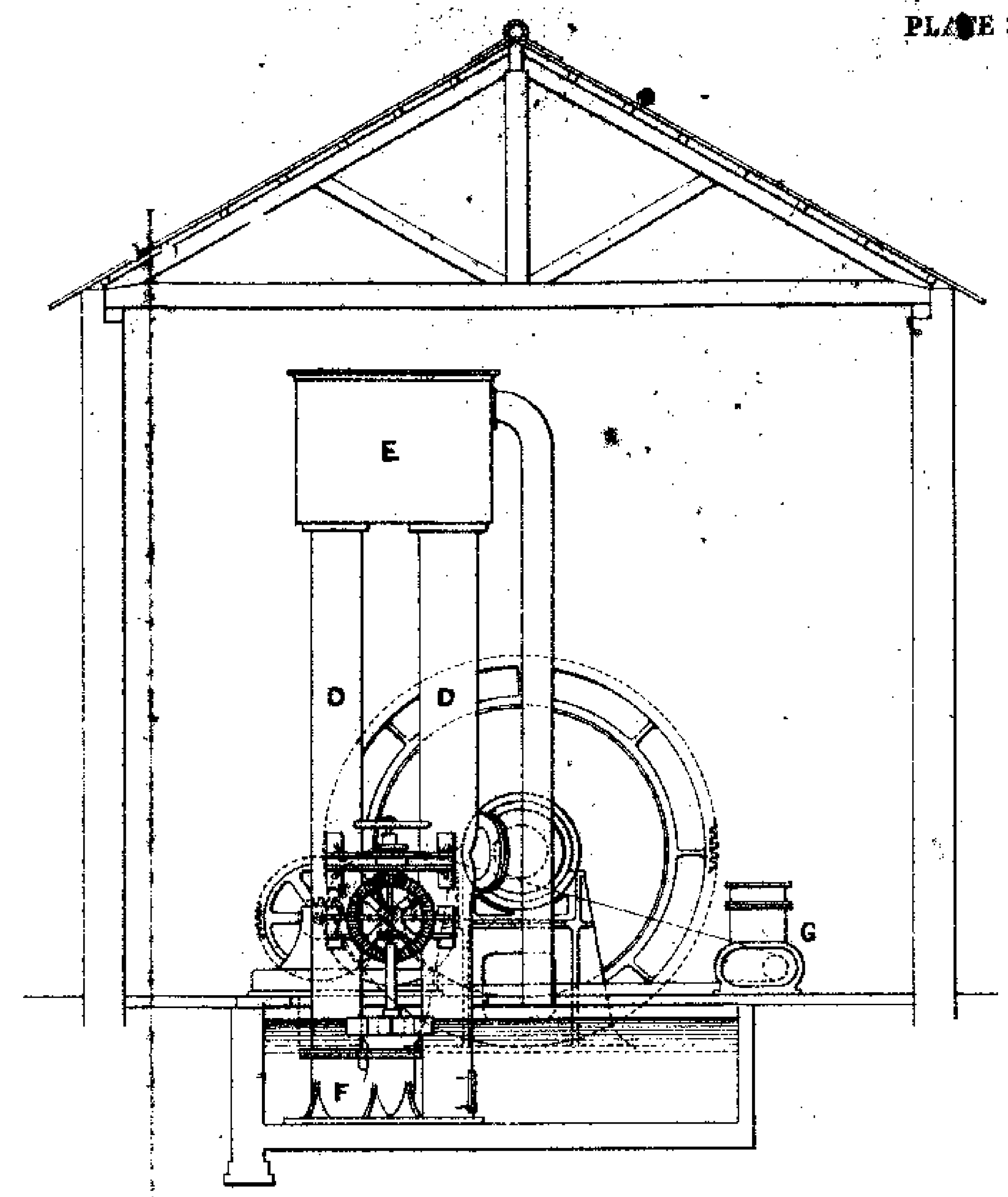
ARRANGEMENT OF REVOLVING PURIFIERS.

KELL & SON, LITH 40 KING ST COVENT GARDEN.

A.B. *Inlet Pipes and Tank.*
C. *Revolving Purifier.*
D.E. *Outlet Pipes and Tank.*
F. *Reaction Wheel.*
G. *Air Blower.*
H. *Perforated Bottom.*







DORDRECHT WATER WORKS.

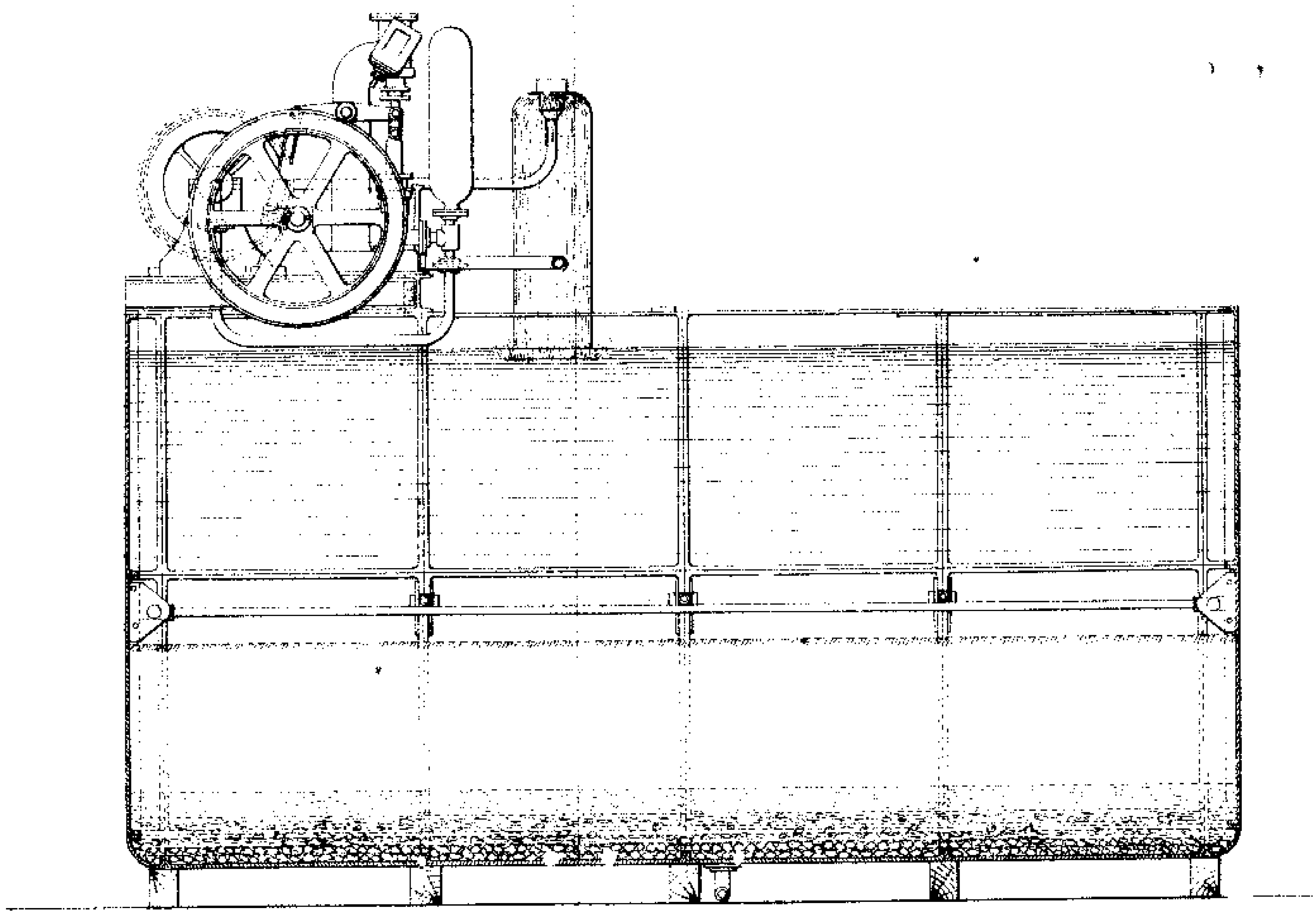
GENERAL ARRANGEMENT OF

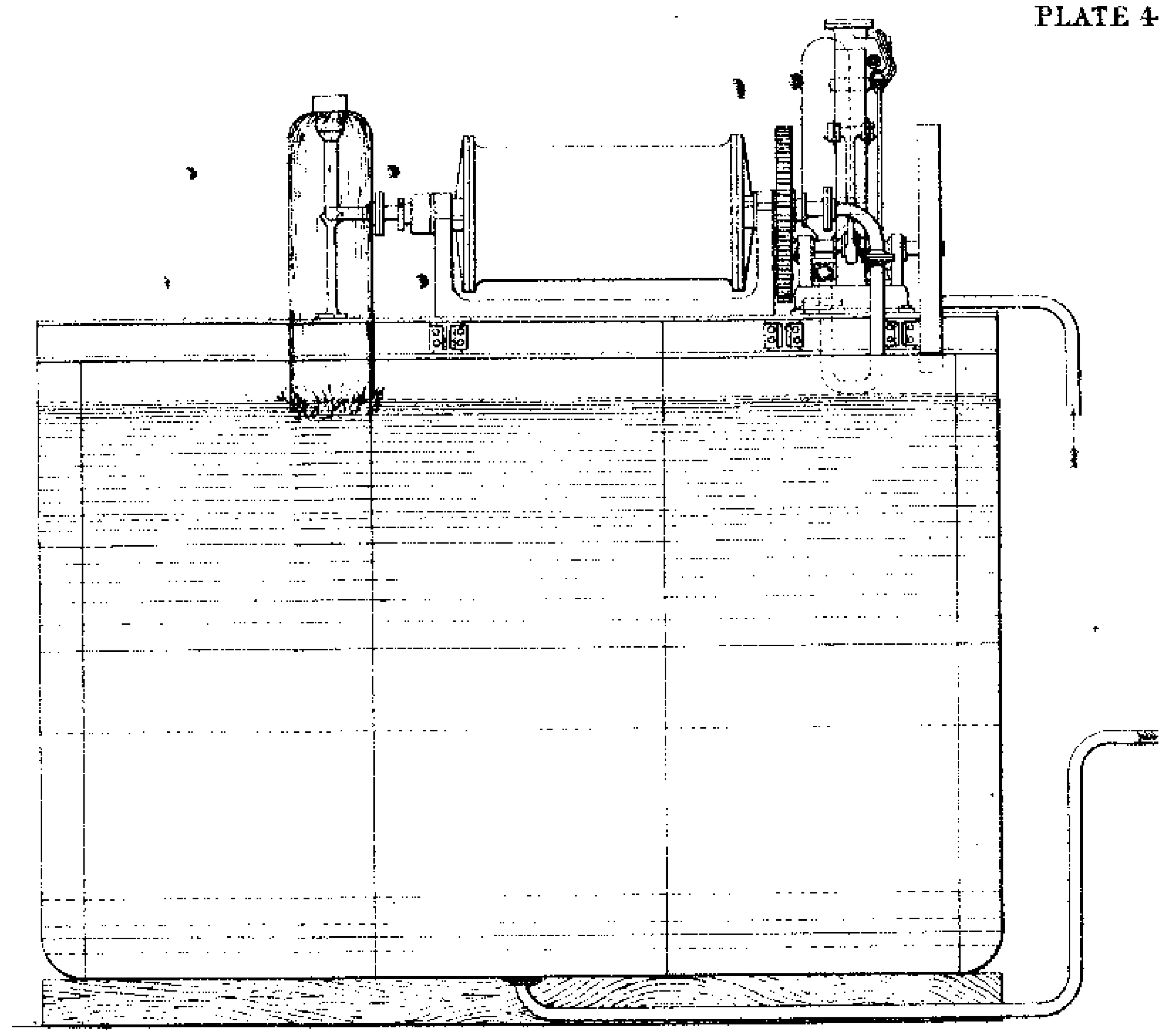
REVOLVING PURIFIER AND MOTOR

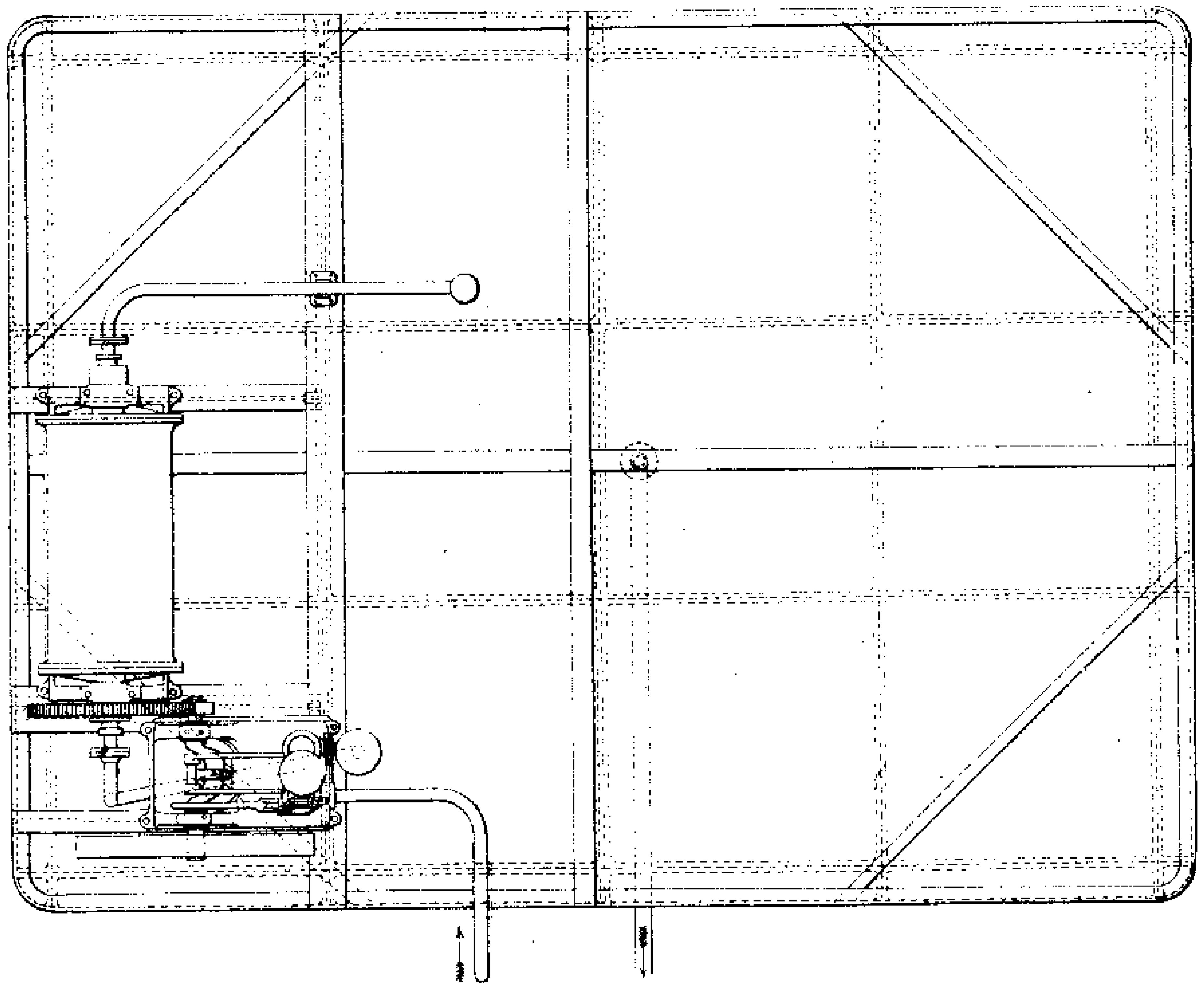
Scale

0 1 2 3 4 5 6 7 8 9 10 Feet

THOS KELL & SON, LITH 40 KING ST COVENT GARDEN.







GENERAL ARRANGEMENT OF

REVOLVING PURIFIER, MOTOR AND SAND FILTER

FOR FACTORIES AND OTHER SMALL SUPPLIES.

THOS KELL & SON, LITH 40 KING ST COVENT GARDEN.

ANTWERP WATER WORKS.

GENERAL ARRANGEMENT OF PURIFIERS, FILTERS AND RESERVOIRS.

A. *Floating Suction*
B. *Screw Pump*
C. *Revolving Purifier*
D. *Aerating Trough*
E. *Regulating Weirs*
F. *Aerating Cascade*
G. *Sand Filter*
H. *Pure Water Tank*
I. *Main Pump*
J. *Flushing Pipe*
K. *Sand Filter*
L. *Reservoir Nº 1.*
M. *Reservoir Nº 2.*
N. *Reservoir Nº 3.*

THOS KELL & SON LITH 40 KING ST COVENT GARDEN